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MODEL STUDIES OF LARGE VENTED OPENINGS — PHASE I

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MODEL STUDIES OF LARGE VENTED OPENINGS — PHASE I

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Type C

by

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ABSTRACT

To determine the optimum configuration of pits for protecting generators from blast loading, tests were conducted using the NCEL Twelve-Inch Shock Tube. The effects of overpressure and dynamic pressure were considered separately. Overpressure was measured quantitatively by a pressure cell mounted in the bottom of the model pit; dynamic pressure was measured qualitatively by observing the bending of 3- or 4-inch lengths of 1/16-inch solder. For the overpressure tests, the model pit was mounted inside the shock tube. For the dynamic pressure tests, the model pit was mounted outside, at the outlet of the shock tube.

Various parapets and covers (including gratings and special structures) were installed around or over the pit. No parapets or covers were found that appreciably reduce the overpressure in the pit, but all reduce the dynamic pressure to some extent. The parapets make the least reduction, and the gratings the most. Special structures, such as louvres, reduce dynamic pressure by various amounts according to their design, but simplicity and effectiveness make the use of gratings appear more promising.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.
This work sponsored by the Defense Atomic Support Agency

INTRODUCTION

One of the deficiencies observed during full-scale tests of protective shelters was the inadequate design of generator pits, leading to damage of the generators.[1] The investigation reported here discusses model studies of several parapets and covers which can be applied to pits to give greater protection to the equipment within. The model studies were made in a shock tube where the shock was created by a compression chamber and a frangible diaphragm.

The task is divided into two phases: Phase I is a study of the optimum pit configuration for generator protection; Phase II is a study of optimum locations (including pits) of generators relative to a protective shelter, and will consider such factors as generator size, operational dependability, air requirements, and blast overpressure range. Only Phase I is discussed in this report; Phase II will be reported separately.

This investigation was sponsored by the Defense Atomic Support Agency through the Bureau of Yards and Docks.

EQUIPMENT

The equipment (Figures 1a and b) consisted of a compression chamber; the shock tube; the model of the pit, including any attachments thereto; and the necessary instrumentation. The shock was generated by breaking a frangible diaphragm, releasing air from the compression chamber. The compression chamber was a 60-cubic-foot cylindrical tank of somewhat greater cross-sectional area than the shock tube itself. It could withstand pressures in excess of 100 psig, but most of the tests were made with pressures of 50 psig as a safety precaution against rupturing the shock tube. Chamber pressures of 50 psig give an overpressure of about 10 psig in the tube, itself.

The shock tube was 1 foot square and 38 feet long. It was made of seven 5-foot sections, plus a 3-foot model section, and could be shortened by omitting sections. For the tests, the shock tube was anchored to a 24-inch I-beam after the length and permanent location of the model section had been determined.

A mylar diaphragm, 8 inches in diameter, separated the shock tube from the compression chamber. Two layers of mylar, each about 0.005 inch thick and capable of withstanding 45 to 50 psig, were used in these tests. For convenience, when the pressure approached the natural breaking point, the diaphragm was broken by a wax projectile shot from a modified .22 caliber rifle.

The effects of overpressure were studied with the model section mounted at the end of the shock tube. The model section was 3 feet long, with a pit 30 inches long, 12 inches wide, and 10 inches deep, mounted in the bottom. The pit could easily be reduced in size. In most of the tests, the pit was 9 inches wide, 18-3/4 inches long, and 9-1/2 inches deep.

To keep the overpressure from decaying too rapidly, a choke (Figure 2) made of several layers of metal lath was fastened to the end of the shock tube. This choke increased the positive-phase duration from about 40 milliseconds to about 400 milliseconds. The overpressure was measured by four pressure cells and recorded on an oscillograph. These pressure cells could be installed along the side of the shock tube, at a number of locations provided, and on the side and bottom of the model section.

The effects of dynamic pressure were studied with the model pit mounted on a horizontal plane surface directly downstream from the outlet of the shock tube (Figure 1b). At this location, the dynamic pressure was about as strong as inside the shock tube, but there appeared to be more freedom from questionable aerodynamic behavior. During most of the tests the pit was mounted in a surface 36 inches wide and 40 inches long.

The effects of dynamic pressure were measured by wires of 1/16-inch solder mounted as cantilevers on a suitable base (Figure 3). The wires in this matrix bend more or less according to the dynamic pressure and, within their obvious limitations, provide a satisfactory method for qualitative measurement of dynamic pressure and prediction of probable generator damage. They interfere very little with the aerodynamic flow and give a picture of the dynamic pressure pattern throughout the pit.

PROCEDURE

Prior to tests, the shock tube and model pit configuration was set up. Fresh sheets of mylar were installed between the compression chamber and the shock tube, and the pressure was built up to the desired value, usually 45 or 50 psig. When the desired pressure was reached, a charge was set off, breaking the diaphragm and allowing the shock to travel down the tube.

When overpressure was measured, pressure cells were installed at selected stations along the shock tube and in the pit, and their outputs were recorded on the oscillograph. When dynamic pressure was measured, wire matrices were installed, usually on the side of the model pit but sometimes on the bottom or downstream end. After the shock, the wires were photographed. Since the measurements of dynamic pressure were qualitative only, the photographic record was considered adequate.

PARAPETS AND COVERS TESTED

A number of model pit parapets and covers were tested, and the results were compared with tests on the model pit alone. The construction details of the parapets and covers are given in Appendix A. The overpressure and dynamic pressure tests included:

1. No parapets or covers (Figure 4a).
2. Double-ramp parapet, 1-1/2 inches high, 45-degree slopes, 3-7/8 inches thick along bottom and 7/8 inches thick along top (Figure 4b).
3. Cover with 1-1/4-inch overhanging lip; ratio of area of rectangular opening, A, to maximum possible opening, A_o, = 0.62 (Figure 4c).*
4. Cover with eight rectangular holes; area ratio = 0.62 (Figure 4d).*
5. Cover with array of 1/2-inch holes; area ratio = 0.62 (Figure 5a).
6. Louvres arranged on horizontal plane; area ratio = 0.62 (Figure 5b).
7. Louvres arranged in a pyramid; area ratio = 0.62 (Figure 5c).*
8. Grating; an approximately scaled model of grating used in Nevada Test pits; area ratio = 0.80 (Figure 5d).

DISCUSSION

Equipment

Overpressure Equipment Considerations. Once the shock tube had been designed and built, it was necessary to examine the shock that was obtained, and to consider possible modifications and additions to the shock tube that might result

* Used in dynamic pressure studies only.

in improvement. Figure 6 shows the pickup stations. These are measured in inches along the shock tube, starting from the diaphragm. Figure 7a shows the variation of overpressure with time at stations 52, 202, 293, and 450. When the shock starts down the tube, the front is steep, the top nearly flat, and the decay fairly rapid (about 100 milliseconds), but as the shock travels down the tube, the front gets even steeper, the flat top shortens, and the decay becomes more rapid (about 15 milliseconds). The ideal shape is an instantaneous rise to a maximum followed by a relatively long exponential decay (positive-phase duration). A number of ideas were tested in order to improve the shape. These ideas included reducing the volume of the compression chamber by partially filling it with water; placing a baffle a short distance in back of the diaphragm to control the reflected shock; placing a perforated disc in back of the diaphragm so that more time is required for all of the air to leave the compression chamber; lengthening the shock tube; changing the position of the model section in the tube; examining the breaking properties of the mylar diaphragm; and placing a choke over the end of the tube.

Most of these ideas have little or no effect on the shape of the shock. A 75 percent increase in the length of the tube produces very minor improvement, and, as space was limited, this approach to the problem did not seem promising. There was no question that the best place for the model section is at the end of the tube. It was also determined that if the mylar breaks near its natural breaking point, a better-shaped shock is obtained, but this behavior is by no means critical. Of the ideas investigated, only the choke over the end of the tube provides an appreciable increase in the positive-phase duration. The most satisfactory choke consists of several layers of expanded metal lath (Figure 2). Figures 7a, b, c, and d, show the effect of 0, 2, 4, and 6 layers of this lath and the increase in positive-phase duration obtained.

Dynamic Pressure Equipment Considerations. For dynamic pressure tests, the pit was mounted outside of the outlet of the shock tube in order to eliminate undesirable effects from the sides and top.

The gages ordinarily used for measuring dynamic pressure disturb the aerodynamic flow. However, long thin objects, such as telephone poles, smoke stacks, and electric wires, are quite sensitive to dynamic pressure, but not to overpressure. Thus, it should be possible to measure qualitatively the amount of dynamic pressure by using wires and observing how much they bend when subjected to a shock. The wires must be of suitable length and made of a material that will remain as deflected and not spring back. It was found that 1/16-inch solder is a satisfactory material. After experimenting with this method of determining dynamic pressure, it was discovered that a similar method had been used by the Suffield Experiment Station in Canada.[2]

Figure 8 shows matrices of wires in two of the arrangements used in the tests discussed in this report. In Figure 8a, the wire matrix was mounted on the bottom of the pit; in Figure 8b, it was mounted on the side. The arrow indicates the direction in which the shock was travelling. Figures 9a and b show an arrangement of wires on both the leading edge and in the bottom of the pit before and after a test, respectively. The photographs of wire matrices were usually taken in a special set-up constructed for the purpose, rather than in the model pit, which presented problems of obstruction and lighting.

In the first tests, the wires were of different lengths (Figure 9a). The longer wires bend more easily, and since the longest wires on the leading edge of the pit were not much longer than the shortest wires on the bottom, Figure 9b shows that the dynamic pressure in the pit was less than in the shock tube itself. After the first tests, the wires were kept the same length. In using this method of measuring dynamic pressure there is a threshold pressure, which is difficult to determine, below which the wires will not bend.

While investigating the equipment, tests were made with several sizes of pits: 9 by 18-3/4 inches in plan by 9-1/2 inches deep (Figure 10a); 12 by 15 inches in plan by 10 inches deep (Figure 10b); and 9 by 11-1/4 inches in plan by 10 inches deep (Figure 10c). These figures show a comparison of the pressures in three different size pits. From these figures, the dynamic pressure in the pit appears to be less when the pit is smaller. Actually, the dynamic pressure will be less when the dimension of the pit in the direction of the shock is shorter. In practice, the shape of the pit will probably be determined by the shape of the equipment to be placed in it. However, if the shock can be expected from any direction and several pieces of equipment are to be installed in the same pit, this equipment should be arranged so that the pit opening can be as nearly square and as small as practical.

The aerodynamic behavior of the shock, using the 9- by 18-3/4-inch pit mounted in the open, is shown in Figures 11a, b, and c. Figure 11a shows a vertical arrangement of wires after a test was made. It can be seen that the height of the shock was well maintained. The horizontal arrangement of wires (Figure 11b) shows that the width of the shock at the leading edge of the pit was about the same as the width of the tube, but narrowed and deteriorated somewhat in strength at the trailing edge. Figure 11c shows results of a test made with a cover over the pit to determine if the deterioration in strength at the trailing edge was due to the presence of the pit or to some other cause. With the pit covered, the shock did not deteriorate at the trailing edge but narrowed slightly. This narrowing had been observed previously and was the reason for using a pit 9 inches wide rather than one as wide as the Twelve-Inch Shock Tube. A pit 9 inches wide and 18-3/4 inches long is 1/16 the size of a typical pit used with the microwave towers. It is also about 1 to 6.4 the

size of the pits used at the Nevada Test Site. Figure 11c indicates a satisfactory behavior, and the tests were conducted using the 9- by 18-3/4-inch pit mounted in the open at the end of the shock tube.

Test Results

In the overpressure tests, the compression chamber pressure was 45 psig, and two layers of 0.005-inch mylar were used for the diaphragm. Figures 12a and b show the variation of overpressure with time at pickup stations 293, 412, 450 (over the pit), and 450 (in the pit). Figure 12b shows the result of using a 4-layer choke over the end of the tube. In either case, there was no significant difference between the overpressure in the pit and in the tube itself. Figure 12b is the basic shock shape used in making overpressure tests. Figures 13a, b, c, and d show results with the double-ramp parapet surrounding the pit, the cover with a large number of holes, the reproduced grating, and the flat louvres, respectively. Again, in no case was there a significant difference between the overpressure in the pit and in the tube, and, more important, no variation could be detected in the overpressure in the pit with the different parapets and covers. Because the effect of the parapets and covers on the pit overpressure is so insignificant, tests were not made with the lip, the cover with the eight rectangular holes, or the pyramid louvres.

In the dynamic pressure tests, two layers of 0.005-inch mylar were again used for the diaphragm. As mentioned previously, the pit was on a flat surface at the end of the tube and not in the model section used when studying overpressure.

Figure 14a shows the pattern of flow using a wire matrix in the 9- by 18-3/4-inch pit with no parapets or covers. Wires on the side of the pit show the aerodynamic flow pattern better than wires on the ends, bottom, or elsewhere. The dynamic pressure in the pit was a fraction (perhaps 1/10 or less) of that in the shock itself; the wires in the pit, although much longer, were not bent as much as those on the leading edge of the pit (Figure 11b). Thus, without any parapets or covers, the pit gives good (but not good enough) protection against dynamic pressure. The Ballistic Research Laboratory reports several field and shock tube tests[3] which also lead to this conclusion.

With the double-ramp parapet (Figure 4b) surrounding the pit, the dynamic pressure was reduced sufficiently at the top so that only the wires in the upper right corner were bent (Figure 14b). However, a comparison of the pattern of flow from this test with that from the test using no parapets or covers (Figure 14a) shows that the wires in the bottom of the pit were bent about as much as when no parapet surrounded the pit. The double-ramp parapet, therefore, will not improve the protection if the equipment is mounted on the floor of the pit, but might do so if

the equipment were mounted on pilings. Failure of the wires to bend does not indicate that dynamic pressure is absent, but rather that the dynamic pressure is a small fraction of that in the shock tube, perhaps 1/25 or less.

The next test used a cover with a rectangular opening (Figure 4c). The area ratio (i.e., the ratio of the area of the opening to the area of the completely open pit) was 0.62, requiring an overhanging lip of 1-1/4 inches on all four sides. This cover and its effect on the dynamic pressure can be seen in Figure 14c. The dynamic flow pattern is similar to that when no parapets or covers are used, but fewer wires are bent showing that the flow pattern is about half as wide and suggesting that the dynamic pressure has not been greatly reduced otherwise.

The dynamic pressure can be reduced by decreasing the total area of the openings in the cover or by dividing the total area into a number of smaller areas or by doing both. A cover was constructed with eight rectangular openings (Figure 4d) with an area ratio of 0.62. With this cover (see Figure 15a) very few wires were bent showing that the dynamic pressure is much less than with the unprotected pit and suggests that the total area of the openings should be divided still further. Reducing the area itself was not given much consideration because doing so would also reduce the ventilation.

Next, a cover with a large number of small holes was constructed, still with an area ratio of 0.62 (Figure 5a). Most of the holes were 1/2 inch and a few were 1/4 inch. This cover reduced the dynamic pressure to a value too low to be detected by the wires (Figure 15b). Upon comparing the bending of the wires in Figure 15b with the bending in Figure 14a (no parapets or covers), it seems reasonable to conclude that the protection to equipment in pits with this cover would be practically complete.

Louvres were used in the next group of tests (Figure 5b). In the first of these tests, the louvres were tilted away from the shock tube, and there was no noticeable dynamic pressure in the pit (Figure 16a). Then the louvres were rotated so the shock approached from the side. Figure 16b shows that the protection was much better than might be expected. Because the pit was longer than the tube was wide, the wires had to be placed on the end in Figure 16b. Finally, the louvres were reversed (Figure 16c). Even in this unfavorable orientation, the louvres gave more protection from dynamic pressure than did an open pit (Figure 14a). Nevertheless, the louvres will not be as satisfactory as some of the other covers if protection is required from shocks arriving from any direction. The louvres would also be an expensive cover to construct.

To preclude an unfavorable orientation, a four-sided louvre pyramid (Figure 5c) was constructed. This pyramid was tested lengthwise, crosswise, and edge-on to the shock, and the results are shown in Figures 17a, b, 18a, b, and c. When the pyramid was crosswise or lengthwise to the shock, the dynamic pressure was low, but not as low as with some of the other arrangements. However, edge-on to the shock, the pyramid performed poorly. For this reason, and because it, too, is expensive to construct, the louvre pyramid need not be considered further.

The last cover tested was a scaled reproduction of a grating (Figure 5d) used at the Nevada Test Site. Figures 19a and b show that this grating was at least as effective in reducing the dynamic pressure as were any of the other covers. The damage which occured to the generators in the Nevada Tests[1] was relatively minor from the standpoint of repair, but nevertheless important to shelter operation. However, since the gratings were torn loose by the blast thereby partially uncovering the pits, the possibility that this damage was caused by dynamic pressure cannot be ruled out.

Figure 20 shows the grating as reconstructed from illustrations and other information in Reference 1. From this drawing, the reproduced grating was designed and built to a scale of 1 to 6.4. The openings are small, and the area ratio is 0.80 as compared with 0.62 for the other covers, which should make this grating attractive to use when ventilation requirements for equipment in pits are severe.

Model Study

The justification of the model discussed in this report is given in Appendix B. The geometric scale determines the size of the model relative to the prototype. Whatever the geometric scale, the time changes by the same ratio, but the rest of the pertinent quantities scale the same in the model as in the prototype. For example, the linear dimensions of the pits used in the Nevada Tests were approximately 6.4 times those used in the model discussed in this report. From Figure 12b, the overpressure in the model was 10 psig with a positive-phase duration of 340 milliseconds. The corresponding pressure and positive-phase duration in the prototype would be 10 psig and 2.18 seconds (6.4 x 340), respectively. Using data from Reference 4, these conditions can be shown to approximate those produced 10,000 feet from ground zero by a 1-megaton nuclear air blast at a 6000-foot altitude. There are innumerable other combinations of distance, yield, and altitude which will give the same 10-psig and 2.18-second condition. There is no apparent reason to believe that the relative reduction in dynamic pressure is less for overpressure shocks greater than 10 psig.

FINDINGS

The parapets and covers used in the attempt to reduce the dynamic pressure inside the model pit may be grouped as follows: parapets (double-ramp parapet) surrounding the pit, special structures (louvre, louvre pyramid) and flat covers (rectangular openings, gratings). None of these parapets or covers reduce the overpressure by a measurable amount, pointing to the conclusion that no significant reduction in pit overpressure can be obtained by using any parapet or cover that allows the free flow of air in sufficient quantity to ventilate generators.

The possibility of reducing the dynamic pressure in the pits is more hopeful. All of the parapets and covers reduce the dynamic pressure, but not to the same extent. Parapets surrounding the pit give the least reduction, and it is doubtful if the additional protection to the generator is great enough to warrant their consideration.

Special structures may reduce dynamic pressure by a great or slight amount depending on the design of the particular structure. The louvres and louvre pyramid are not completely satisfactory because their protection is directional. In any case, special structures are elaborate and expensive to construct. Flat covers show more promise because they are relatively simple, economical, and highly effective.

Flat covers can include a multitude of designs, some effective and others not so effective, but most reduce the dynamic pressure in the pit either by reducing the total area of the pit opening or by dividing the pit opening into many small sections. The latter approach is better because the ventilation is reduced much less. The flat covers with several hundred or more small openings are especially effective in reducing dynamic pressure and may reduce the dynamic pressure up to fifty times its value without the cover. Under this circumstance it is difficult to believe that any damage will occur to generators or other equipment.

The limited study of pit sizes and shapes indicates that the narrower the pit perpendicular to the blast, the greater the protection from dynamic pressure. Since the shock could come from any direction, the equipment should be arranged, if possible, so that the pit could be nearly square and as small as practical.

CONCLUSIONS

1. Parapets and covers (grills, gratings, louvres, etc.) which provide a free flow of air sufficient to ventilate generators do not appreciably reduce the overpressure in a pit.

2. Suitable parapets and covers can appreciably reduce the dynamic pressure inside a pit. Of the covers tested, those with a large number of small openings are the most effective.

3. The dynamic pressure inside a pit probably cannot be reduced greatly below that provided by the gratings used in the Nevada Tests (if these gratings are not torn loose).

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3. Ballistic Research Laboratories. Memorandum Report 1279, Changes in Drag Caused by Air Blast Shielding, by G. A. Coulter and W. T. Matthews. Aberdeen Proving Ground, Maryland, June 1960.

4. United States Department of Defense. The Effects of Nuclear Weapons, United States Atomic Energy Commission. Washington, D. C., April 1962.

5. Murphy, Glen. Similitude in Engineering. The Ronald Press Company, New York, 1950.

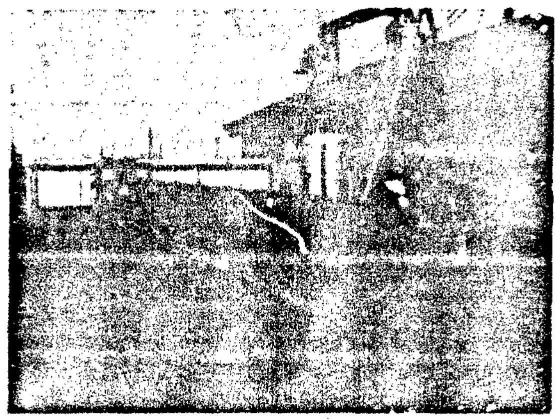


Figure 1a. Twelve-Inch Shock Tube and associated equipment; model section in place.

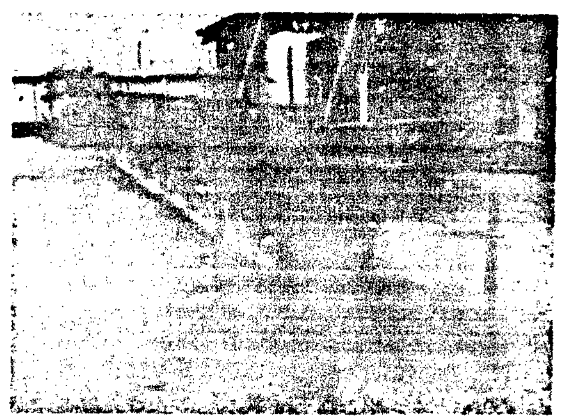


Figure 1b. Open pit installed beyond end of shock tube.

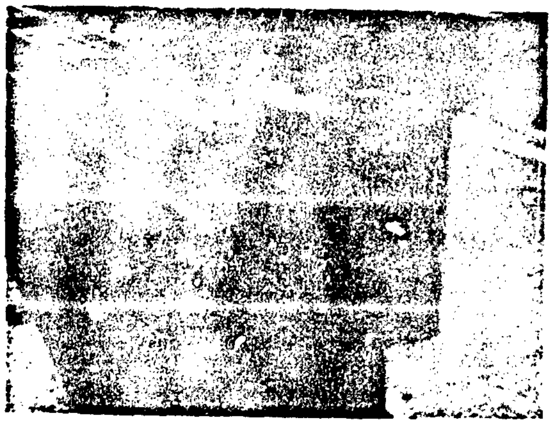


Figure 2. Choke installed on end of shock tube.

Figure 3. Matrix of wires ready for installation.

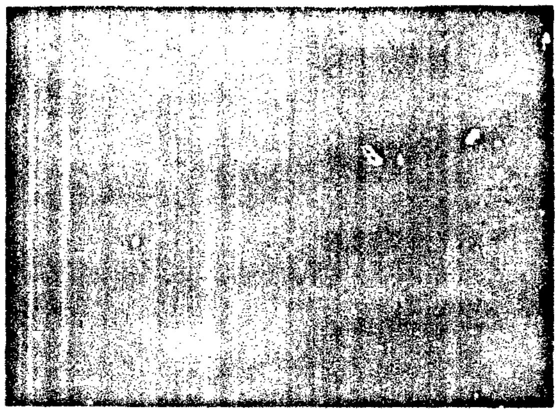


Figure 4a. Pit without parapet or cover.

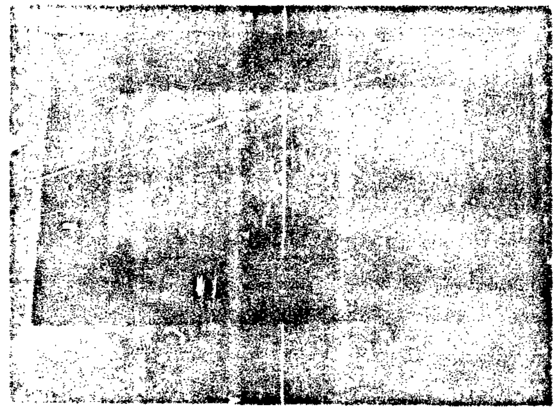


Figure 4b. Double-ramp parapet.

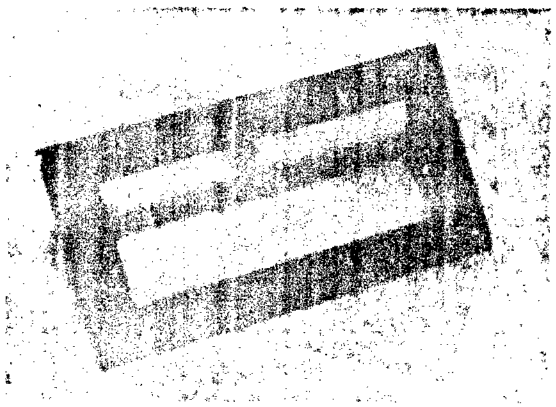


Figure 4c. Cover with 1-1/4-inch lip (A/A_o = 0.62).

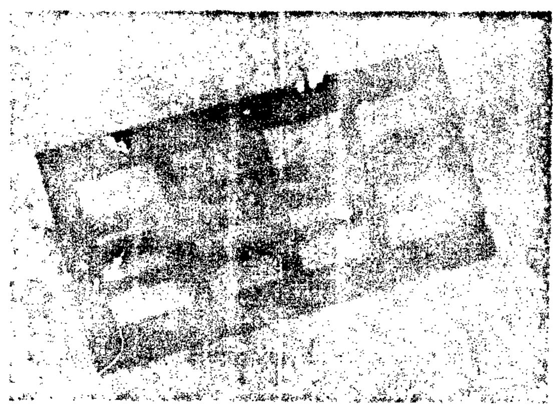


Figure 4d. Cover with eight rectangular openings (A/A_o = 0.62).

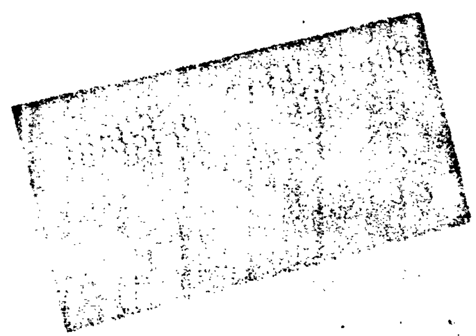


Figure 5a. Grating with a large number of small holes (A/A_o = 0.62).

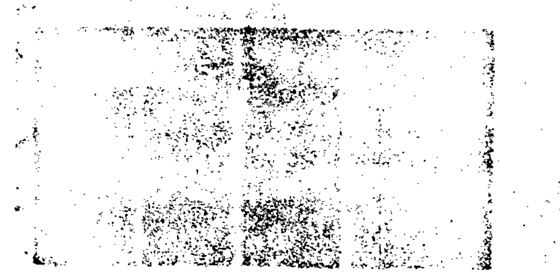


Figure 5b. Flat louvers (A/A_o = 0.62).

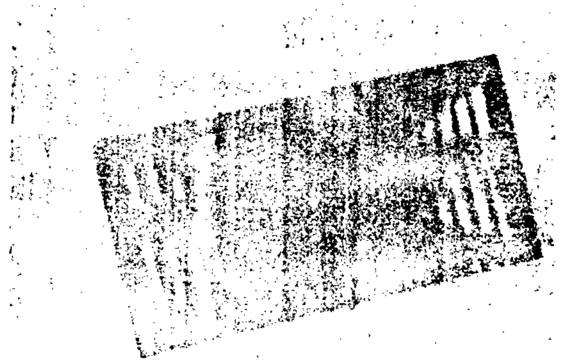


Figure 5c. Pyramid louvers (A/A_o = 0.62).

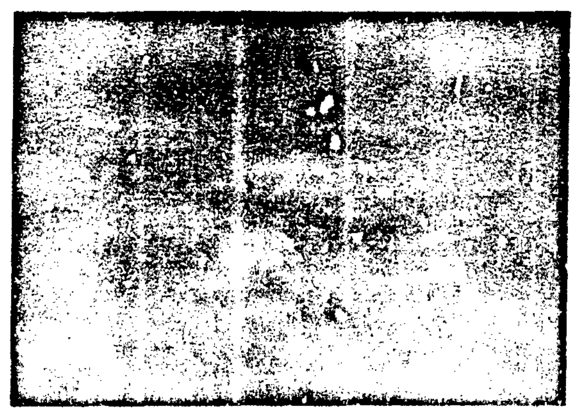


Figure 5d. Reproduced grating (A/A_o = 0.80).

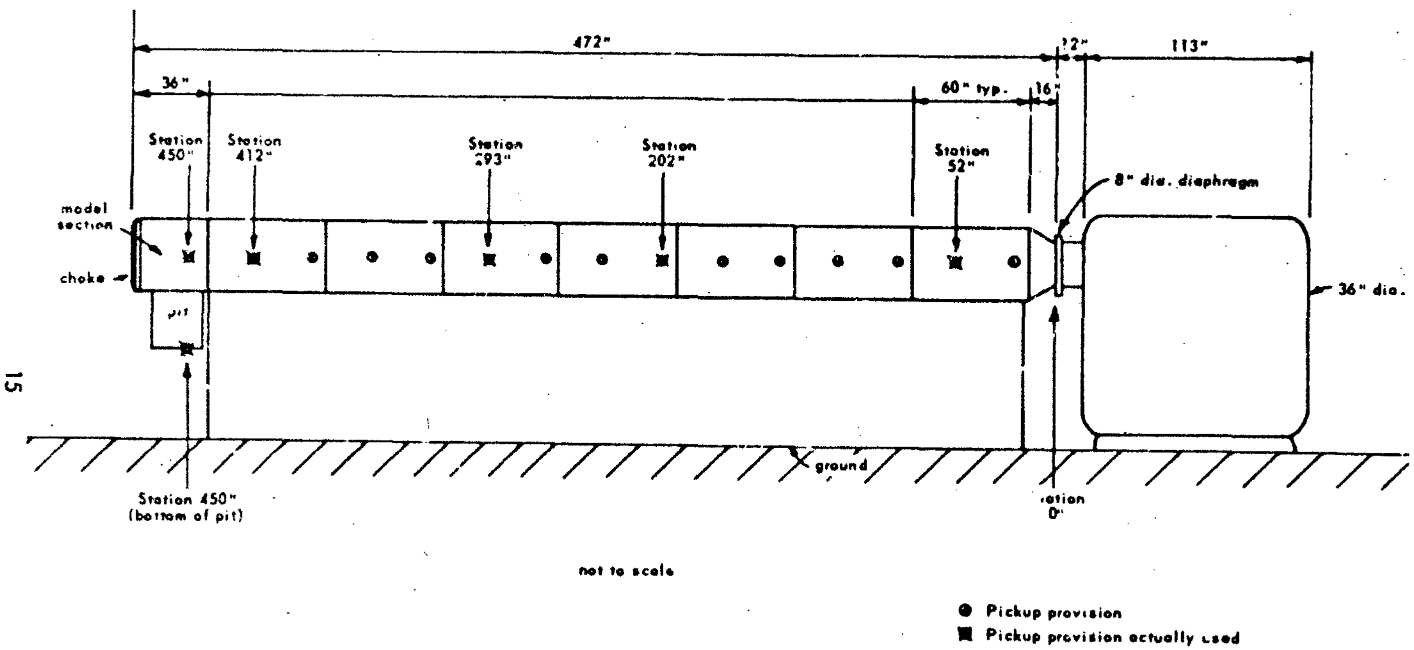


Figure 6. Diagram of 12-inch-square shock tube showing pickup locations.

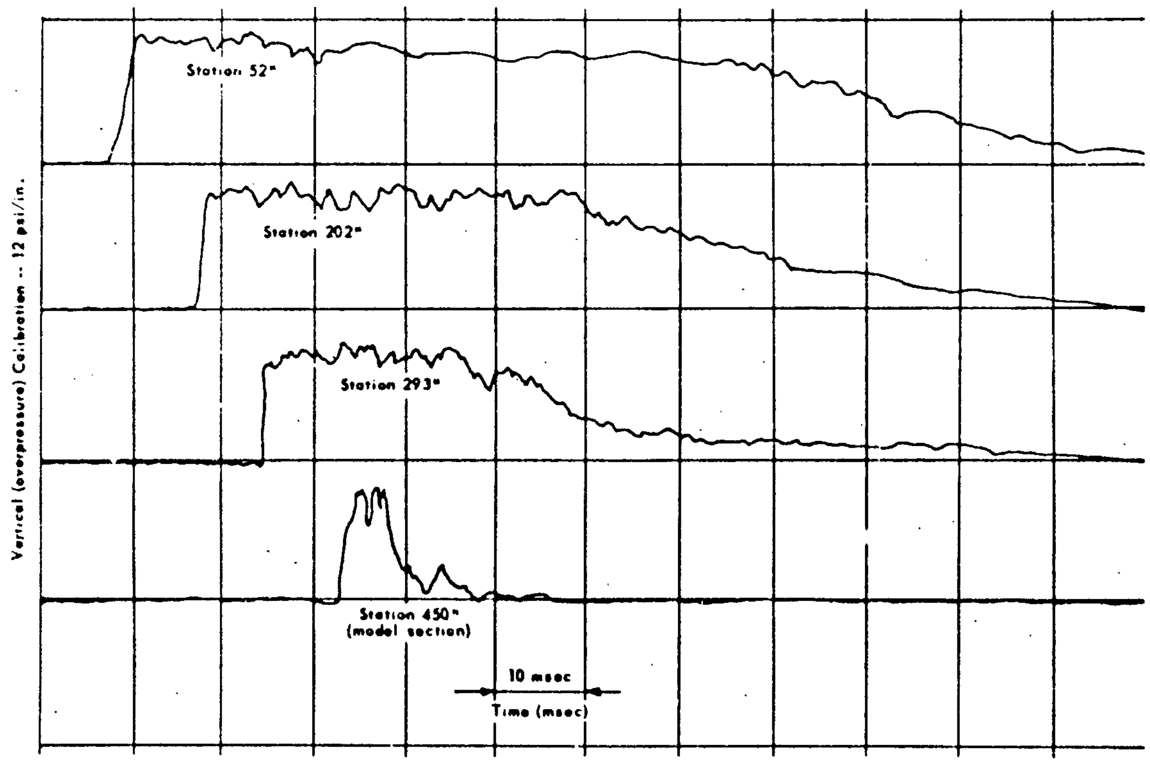
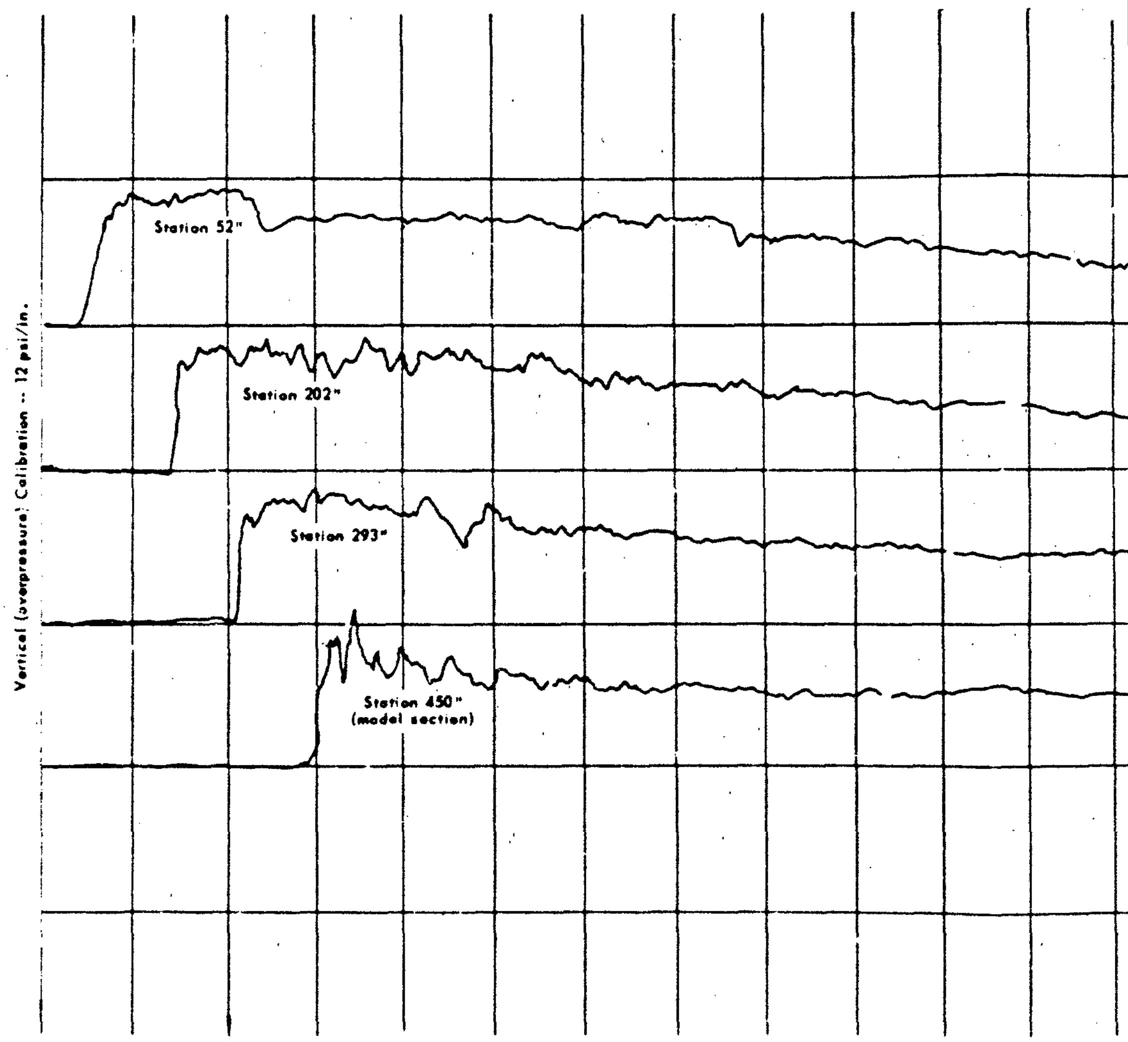


Figure 7a. Typical shock tube behavior without choke.


Vertical (overpressure) Calibration -- 12 psi/in.
Station 52"
Station 202"
Station 293"
Station 450"
(model section)

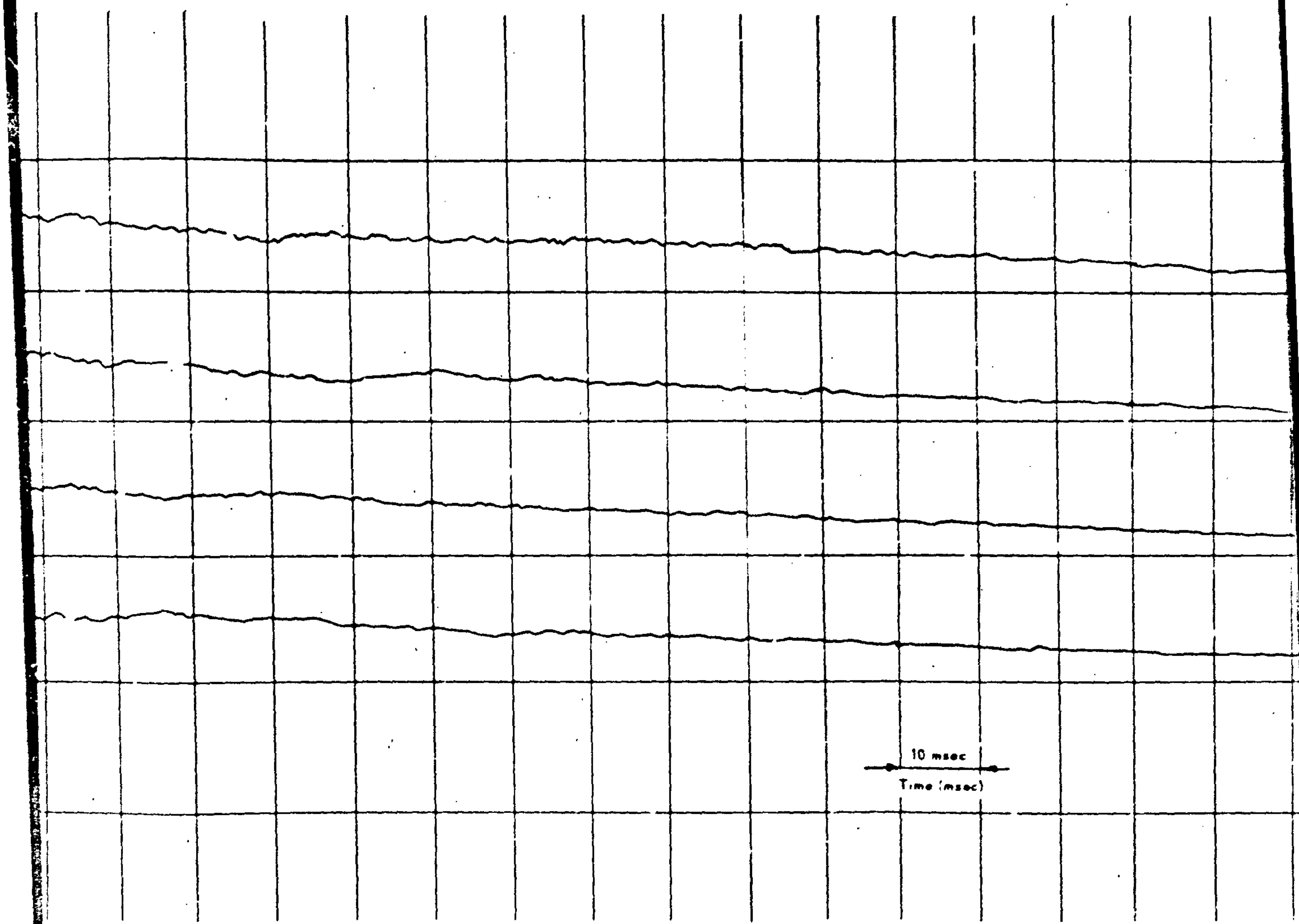


Figure 7b. Typical shock tube behavior with two layer

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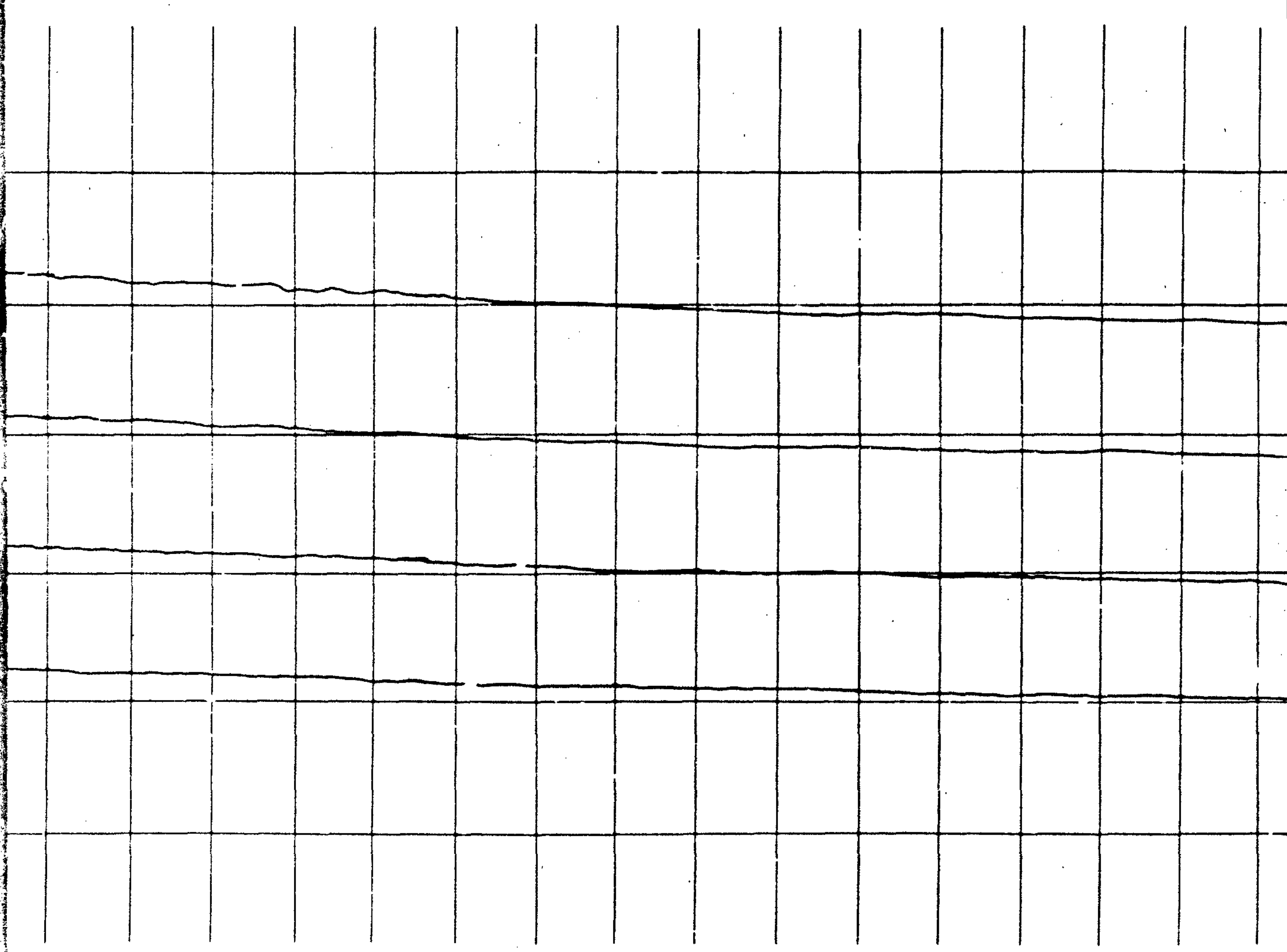

ehavior with two layers of choke.

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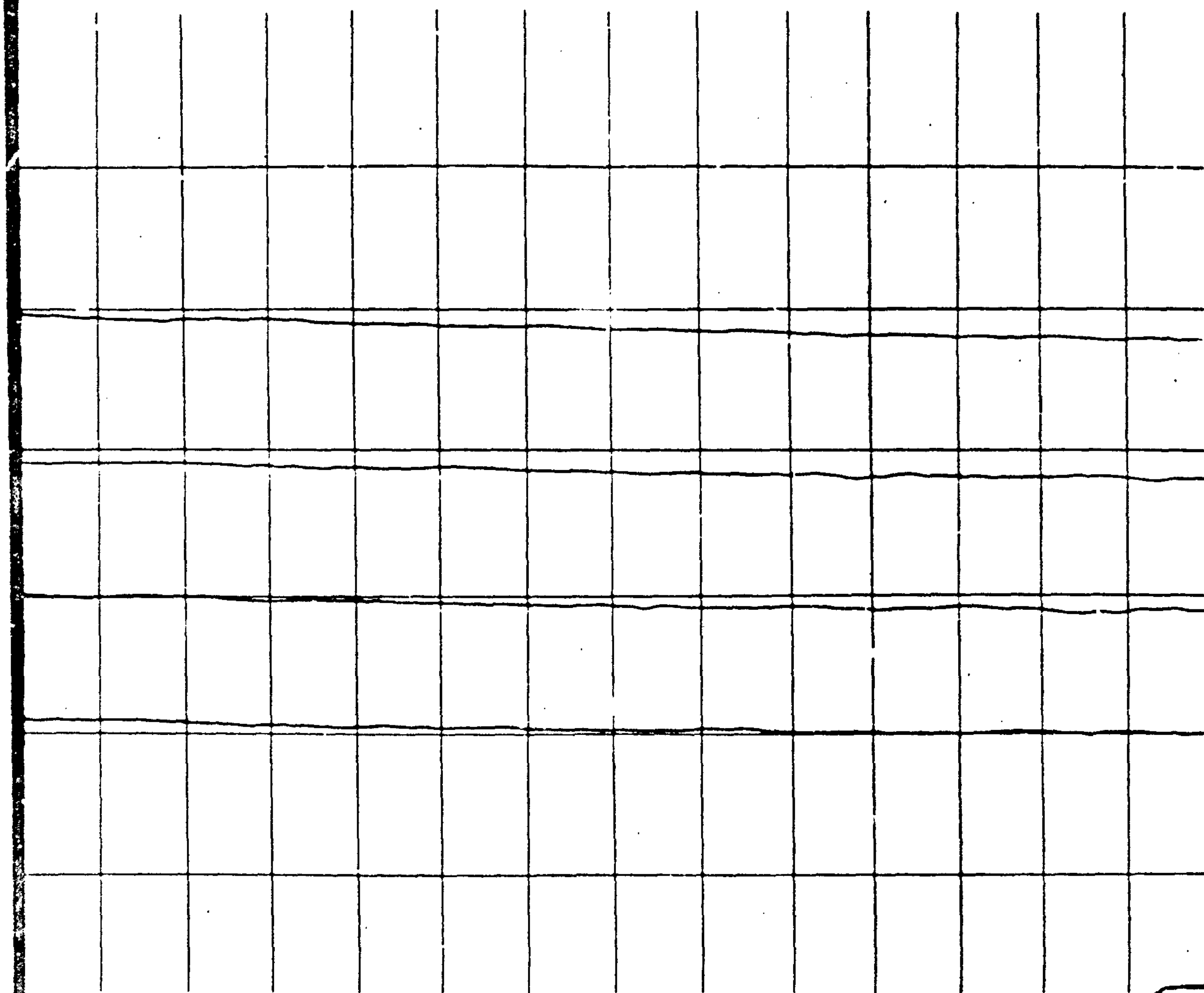

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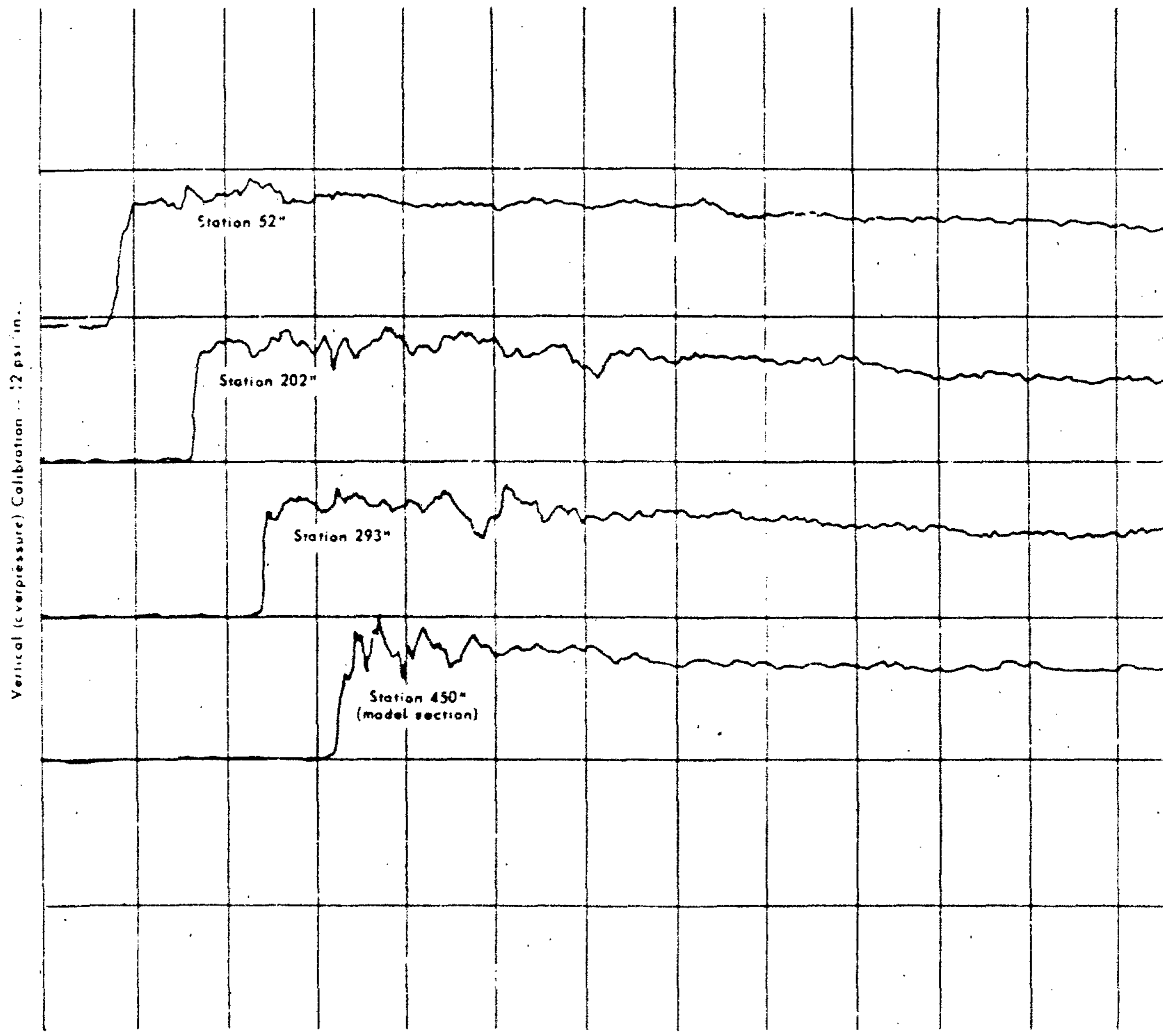
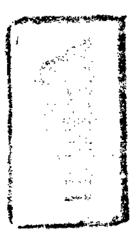

Vertical (overpressure) Calibration - 12 psi/in.
Station 52"
Station 202"
Station 293"
Station 450"
(model section)



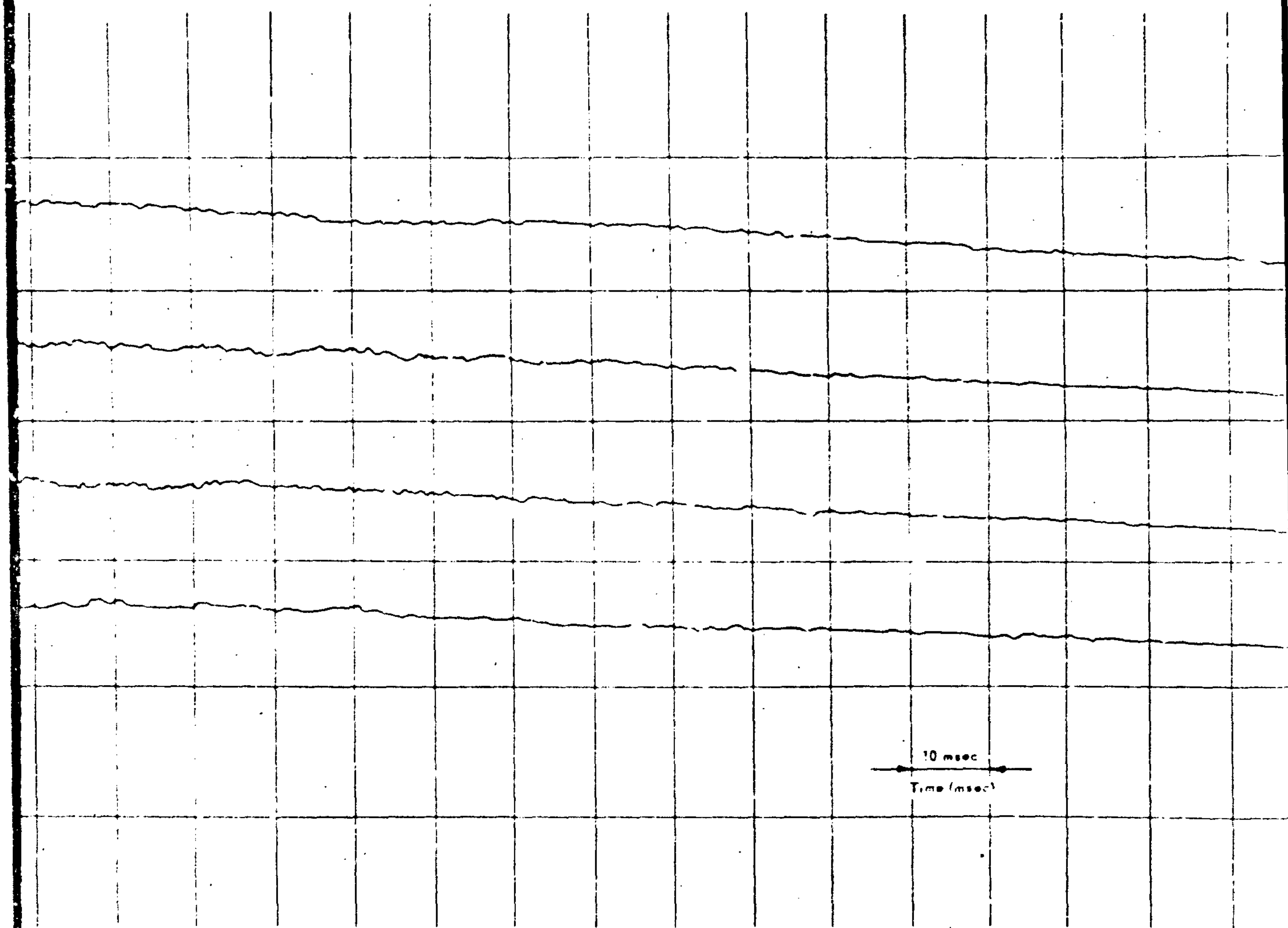
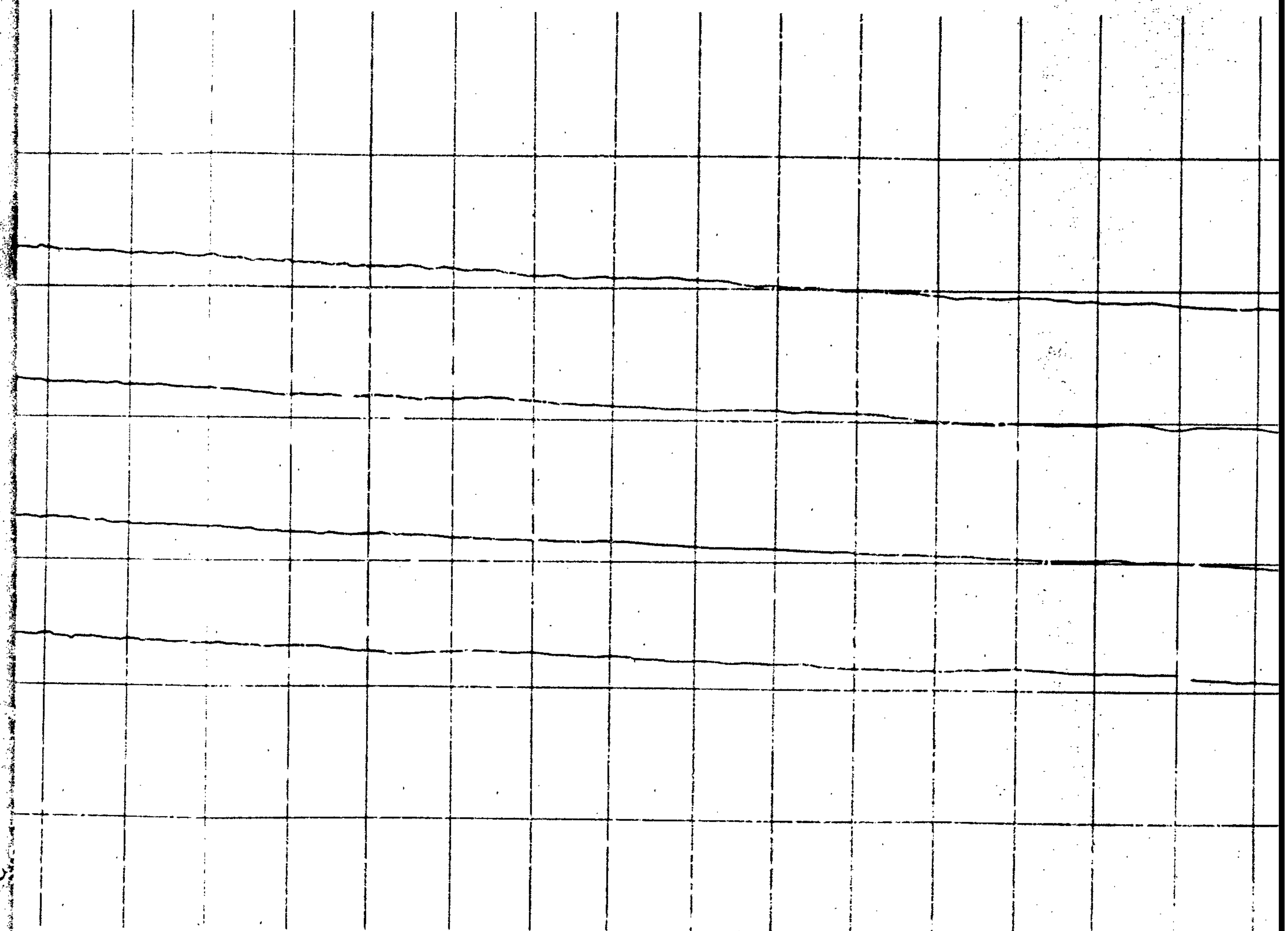
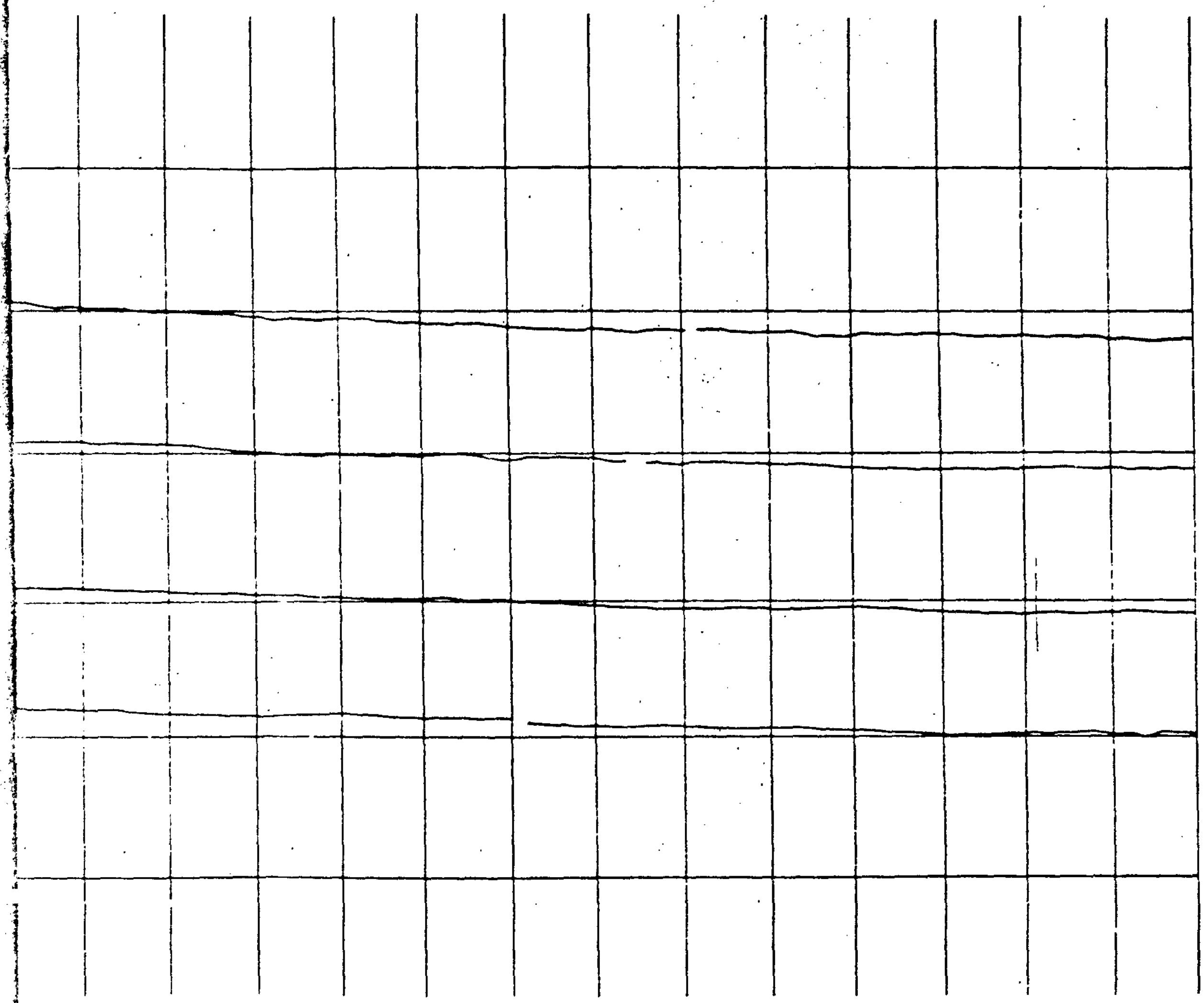


Figure 7c. Typical shock tube behavior with four layers of choke.

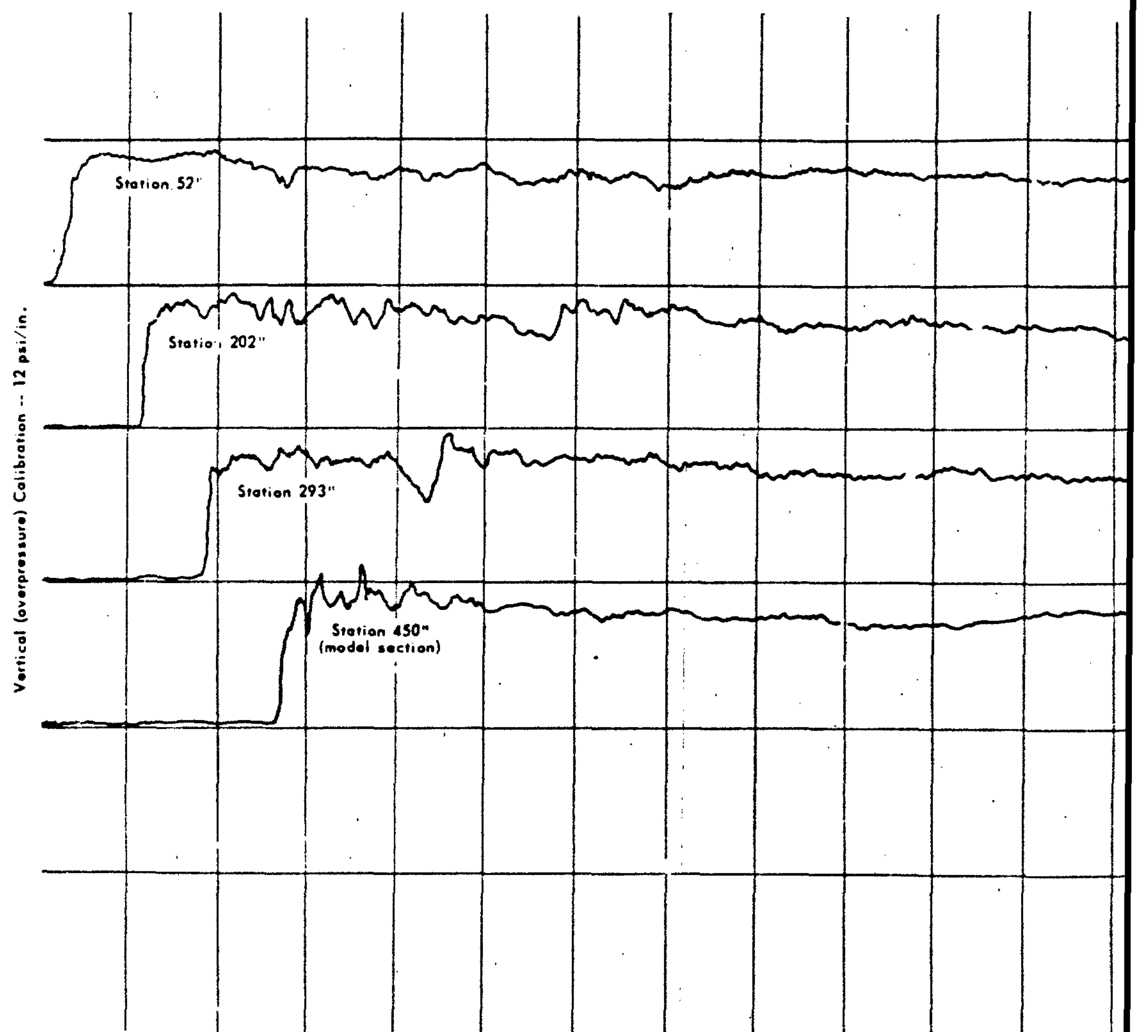
2

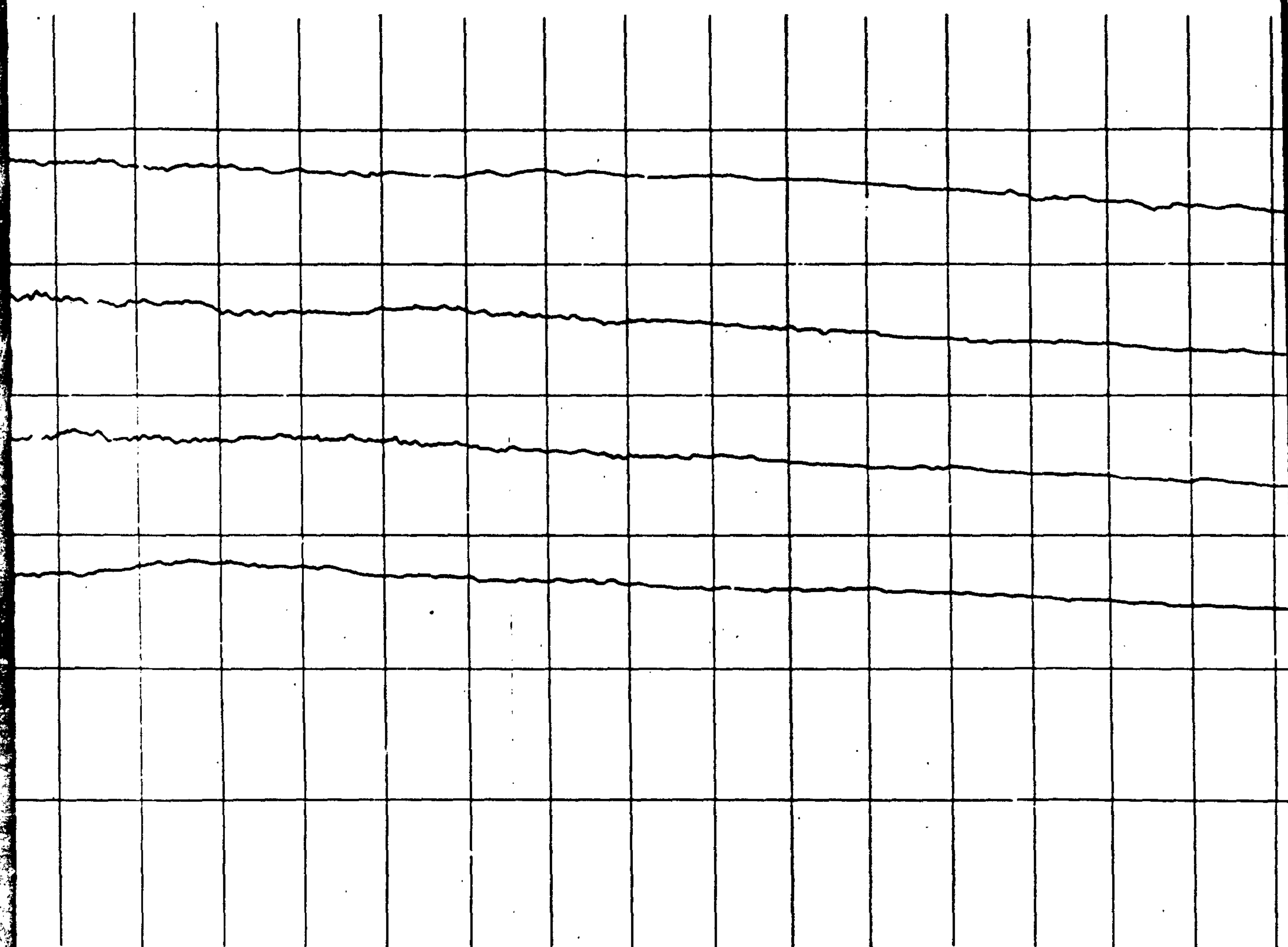


ith four layers of choke.



4


Vertical (overpressure) Calibration -- 12 psi/in.
Station 52"
Station 202"
Station 293"
Station 450"
(model section)



Fi

2

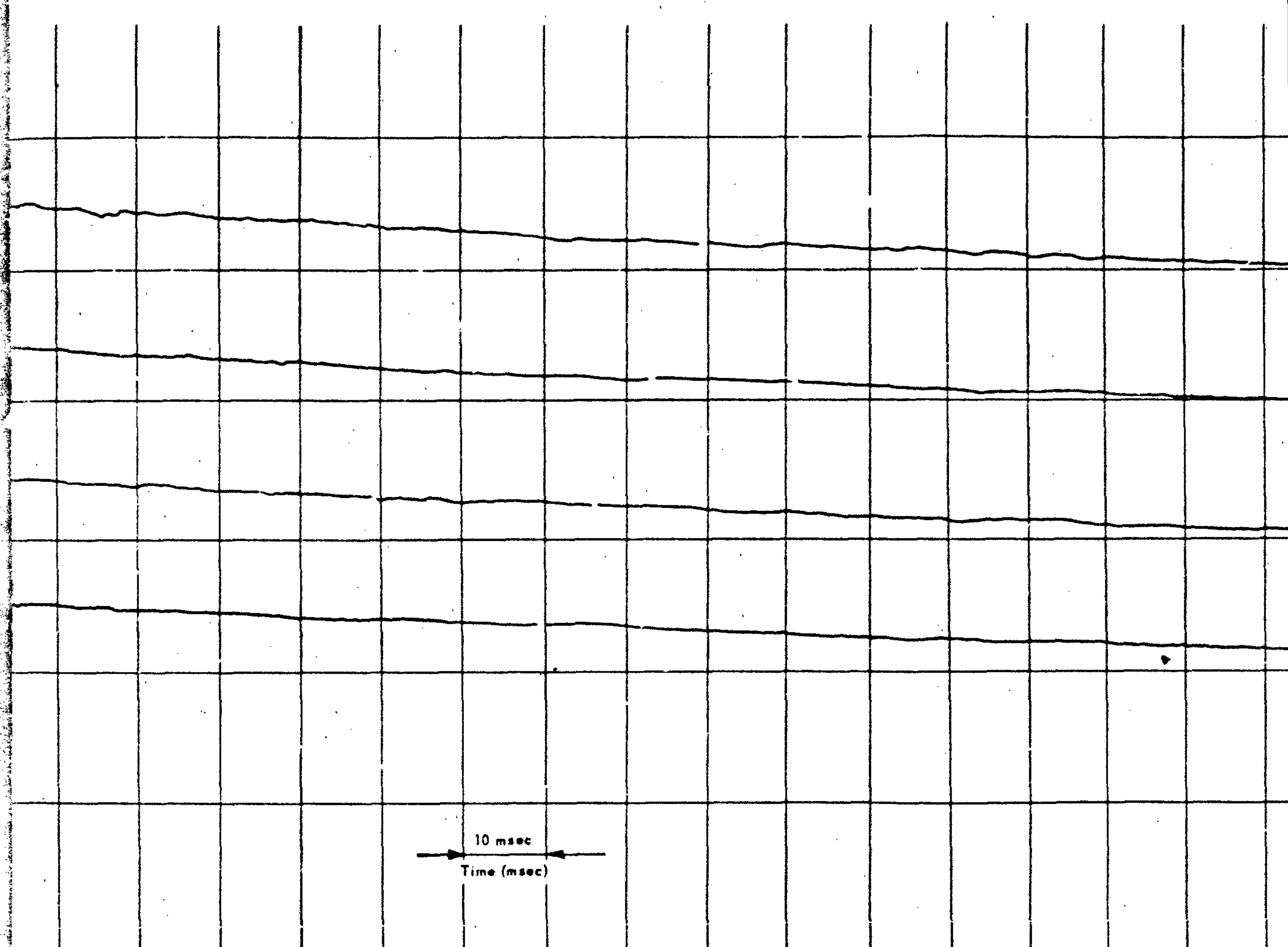
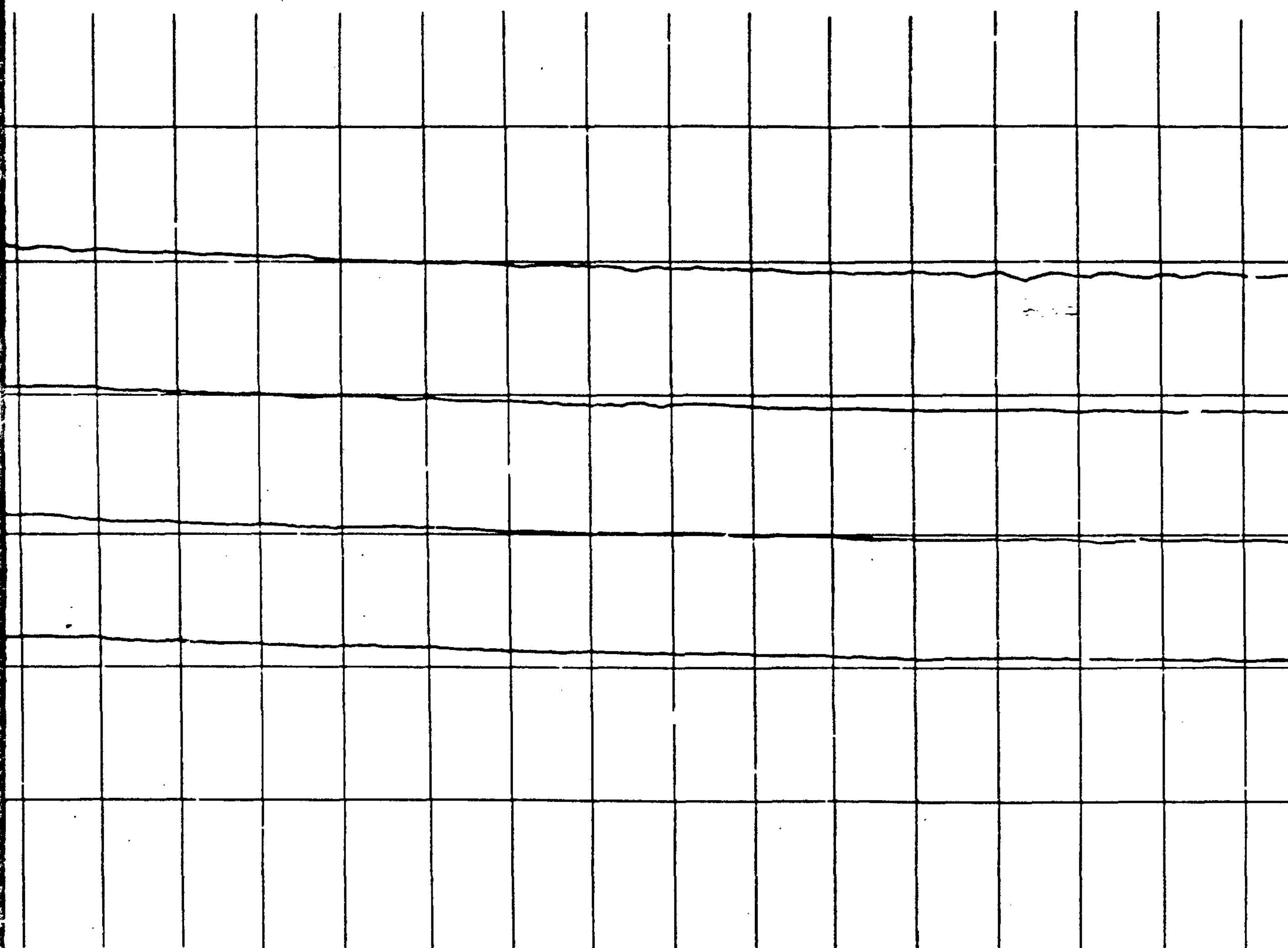


Figure 7d. Typical shock tube behavior with six layers of choke.

3



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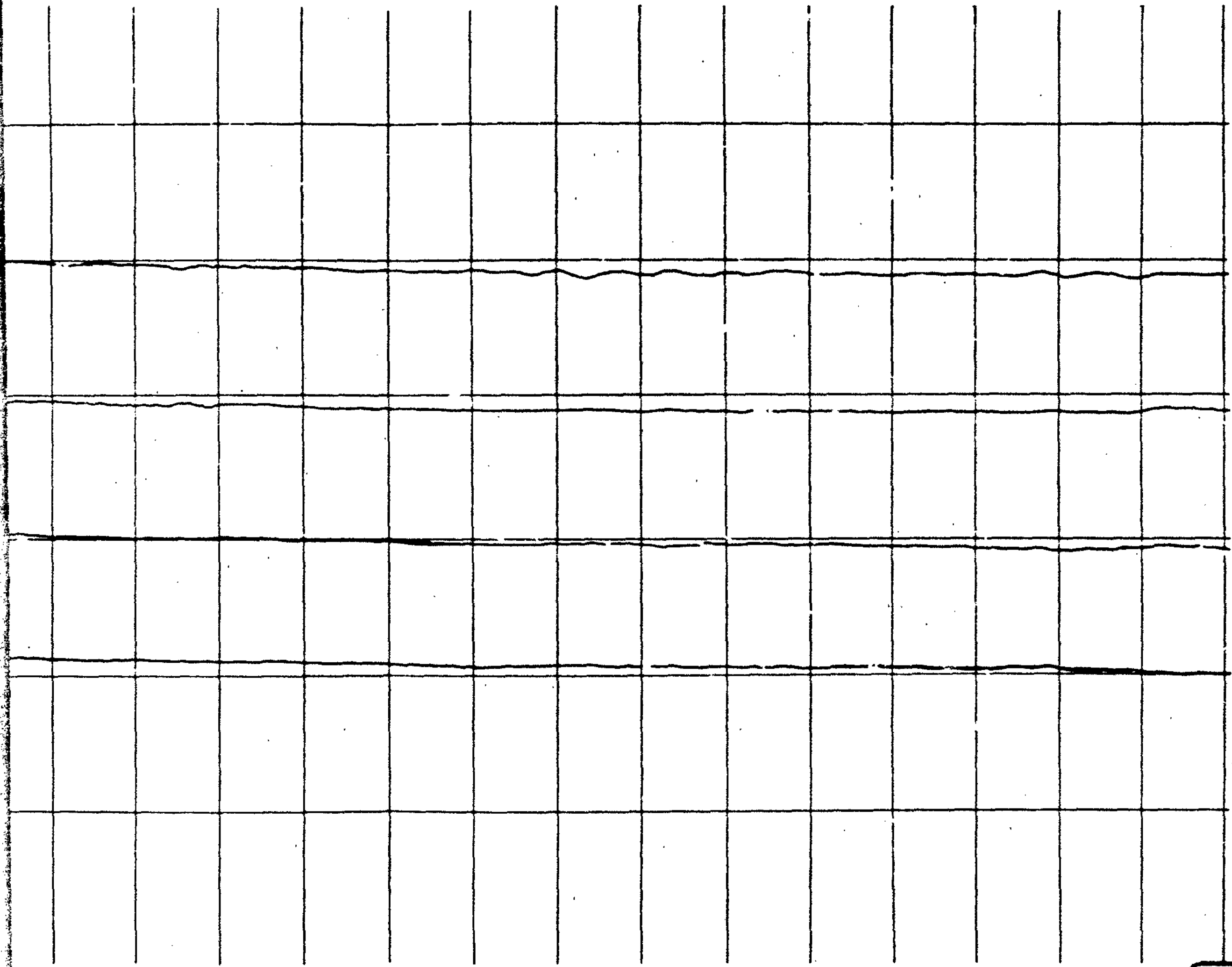

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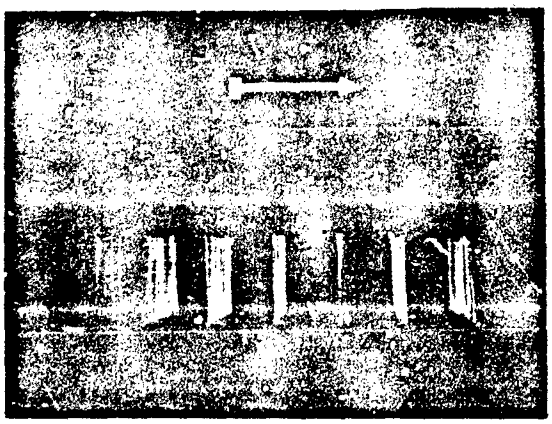


Figure 8a. Matrix of wires mounted on bottom of pit.

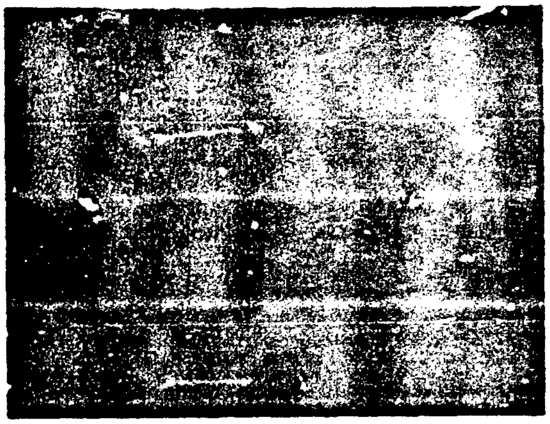


Figure 9a. Wires used in sample test: before test.

Figure 8b. Matrix of wires mounted on side of pit.

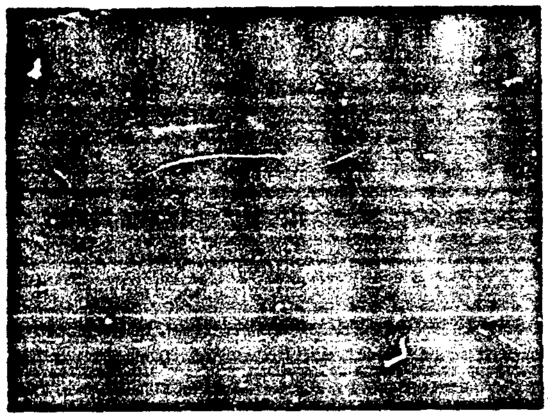
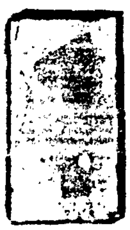
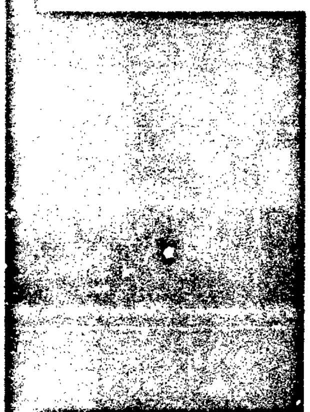


Figure 9b. Wires used in sample test: after test.





sample test: before test.

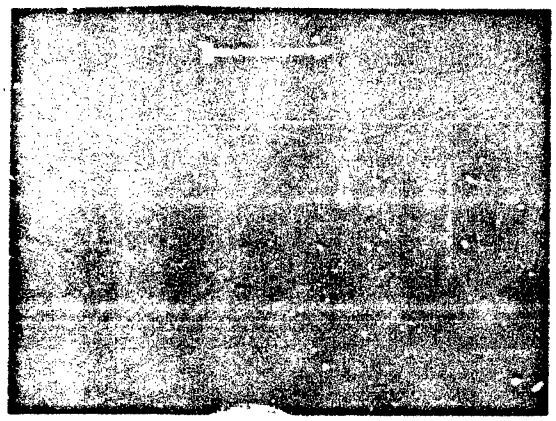
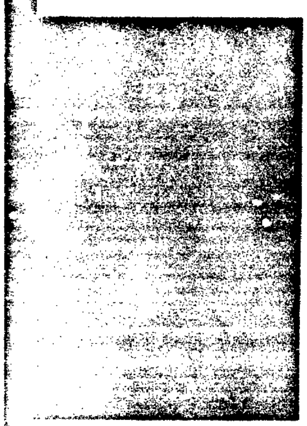


Figure 10a. Dynamic pressure in pit 9 by 18-3/4 inches in plan by 9-1/2 inches deep.

Figure 10c. Dynamic pressure in pit 9 by 11-1/

in plan by 10 inches deep.



sample test: after test.

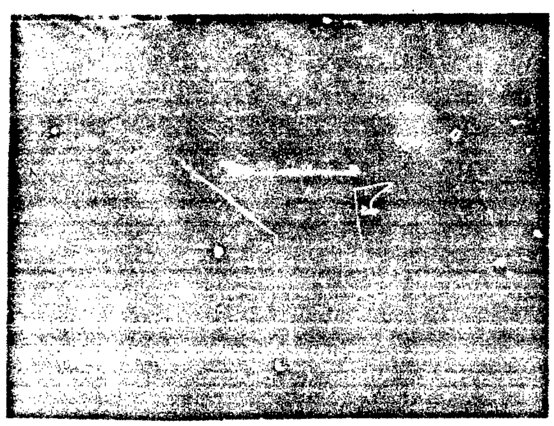


Figure 10b. Dynamic pressure in pit 12 by 15 inches in plan by 10 inches deep.

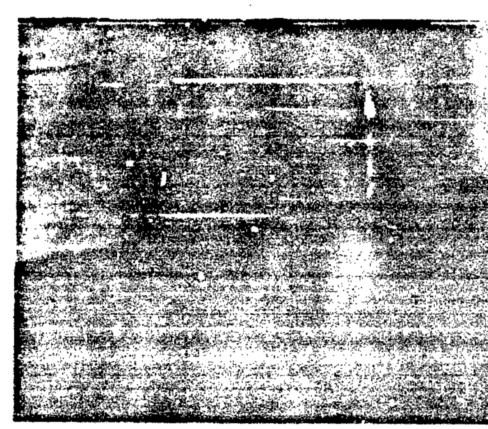
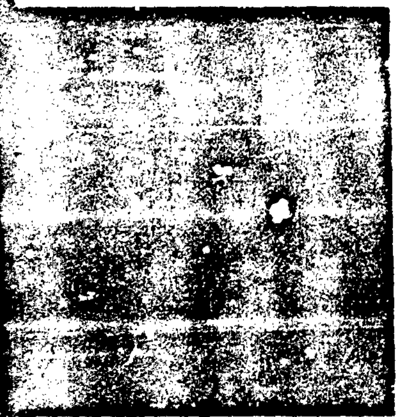


Figure 11a. Vertical flow pattern (open pit

2



ic pressure in pit 9 by 11-1/4 inches
n by 10 inches deep.

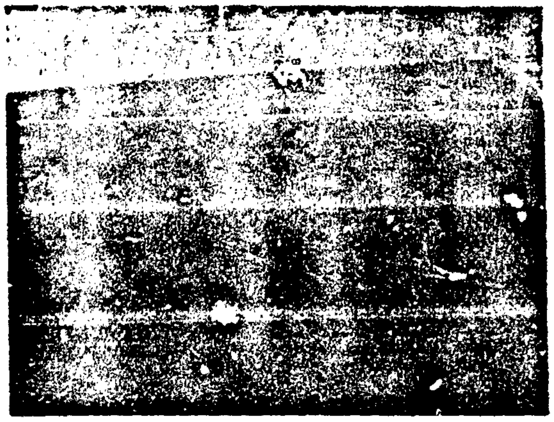


Figure 11b. Horizontal flow pattern (open pit).

/ertical flow pattern (open pit).

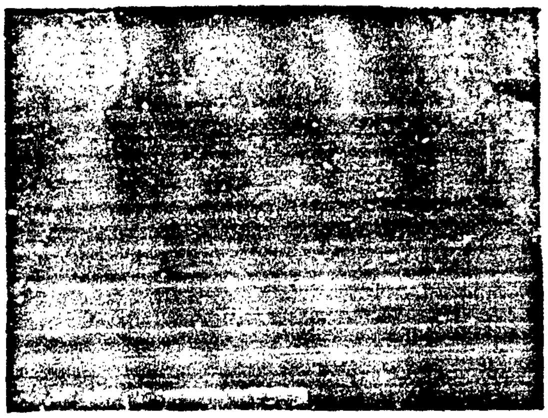


Figure 11c. Horizontal flow pattern (covered pit).

3

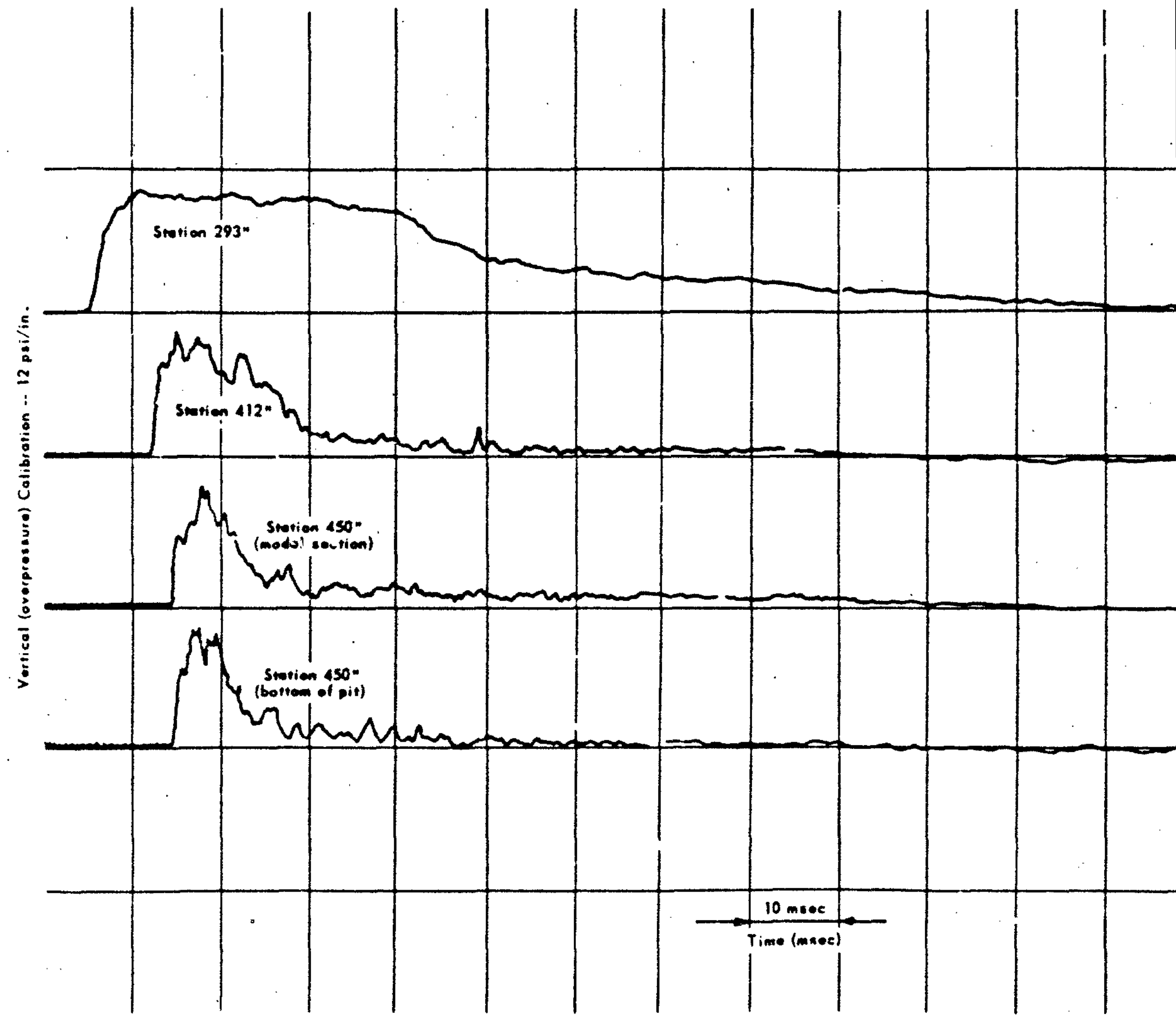


Figure 12a. Overpressure in pit 9 by 18-3/4 inches without choke.

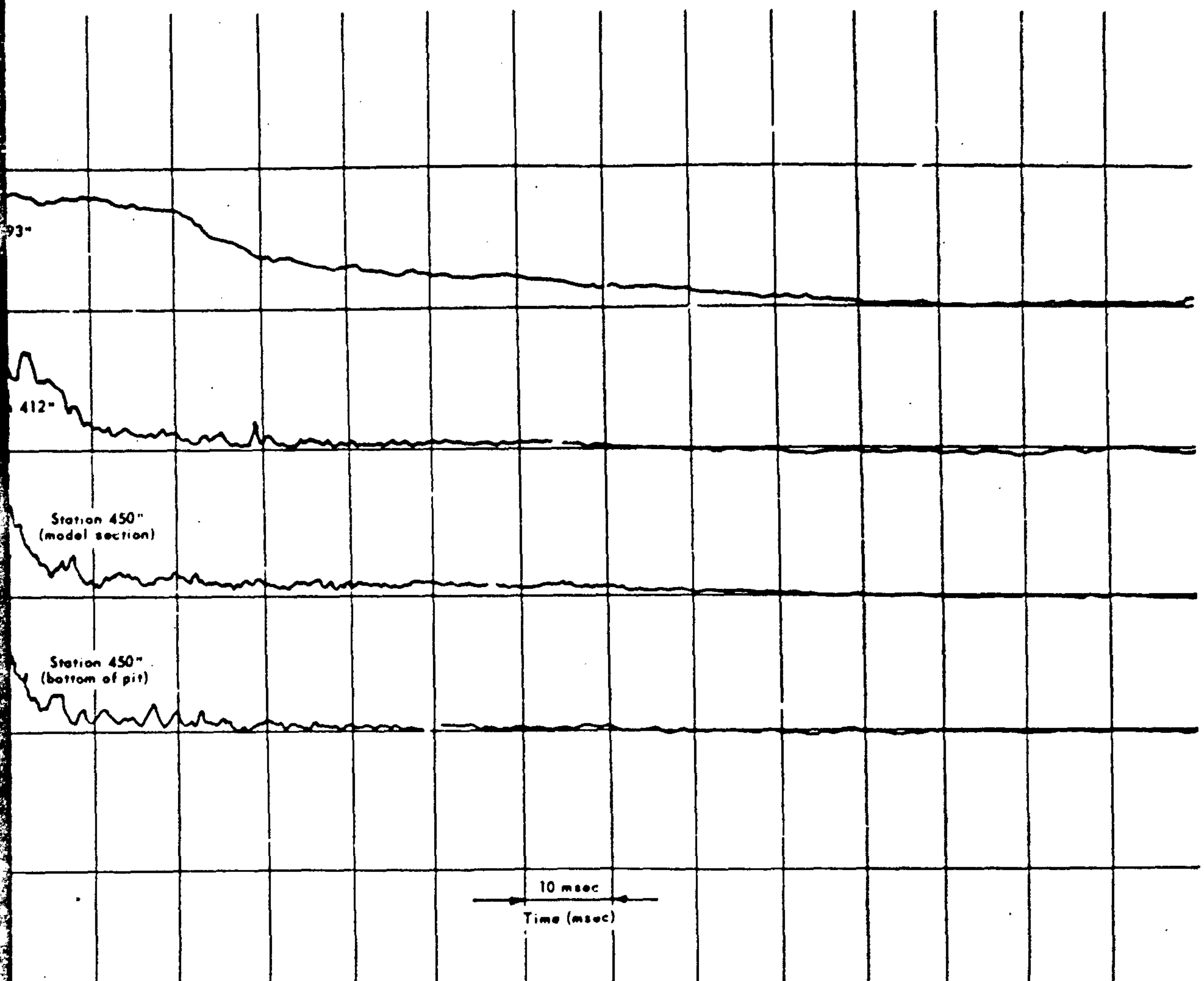
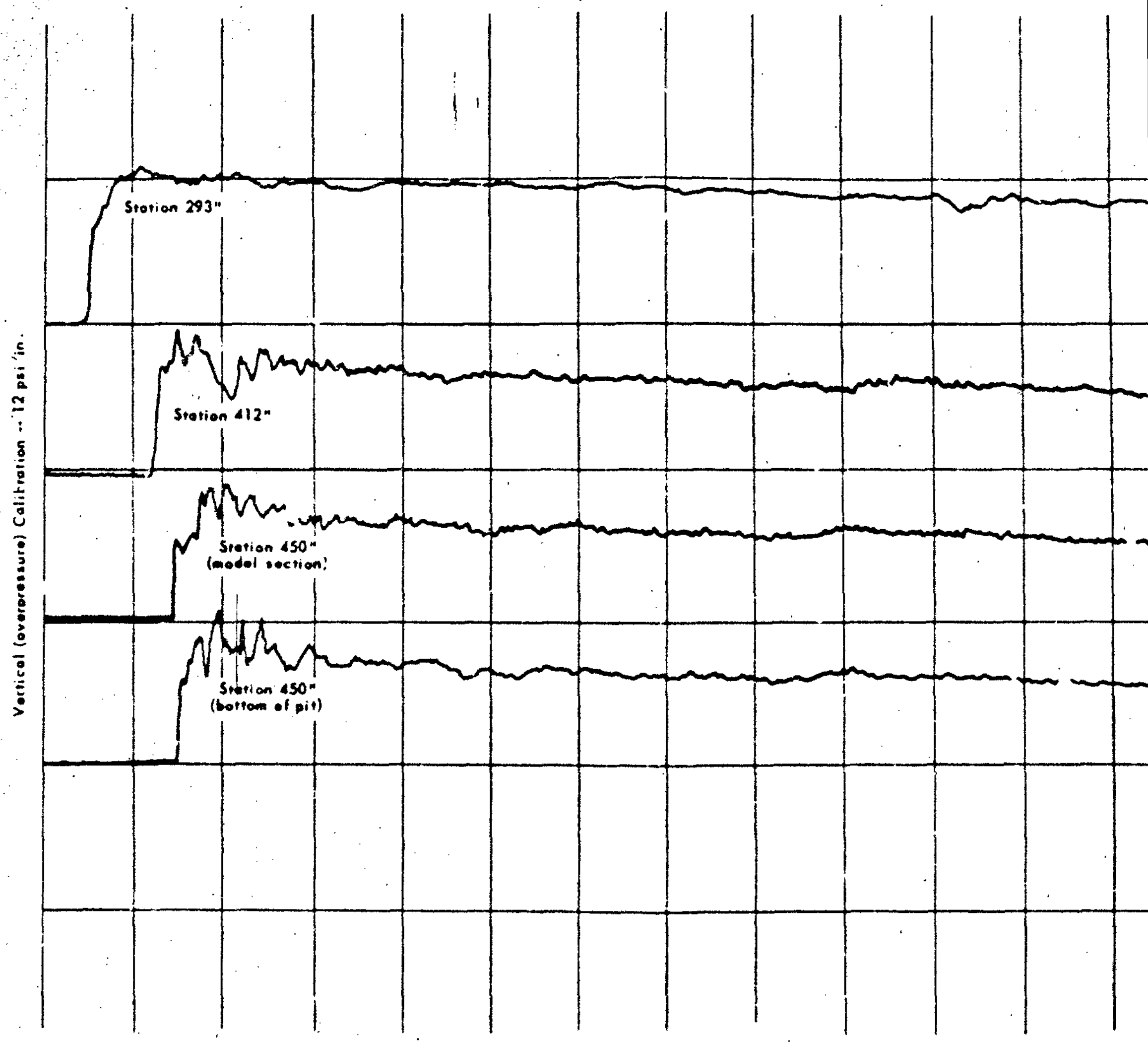


Figure 12a. Overpressure in pit 9 by 18-3/4 inches without choke.

2


Vertical (overpressure) Calibration -- 12 psi/in.
Station 293"
Station 412"
Station 450"
(model section)
Station 450"
(bottom of pit)

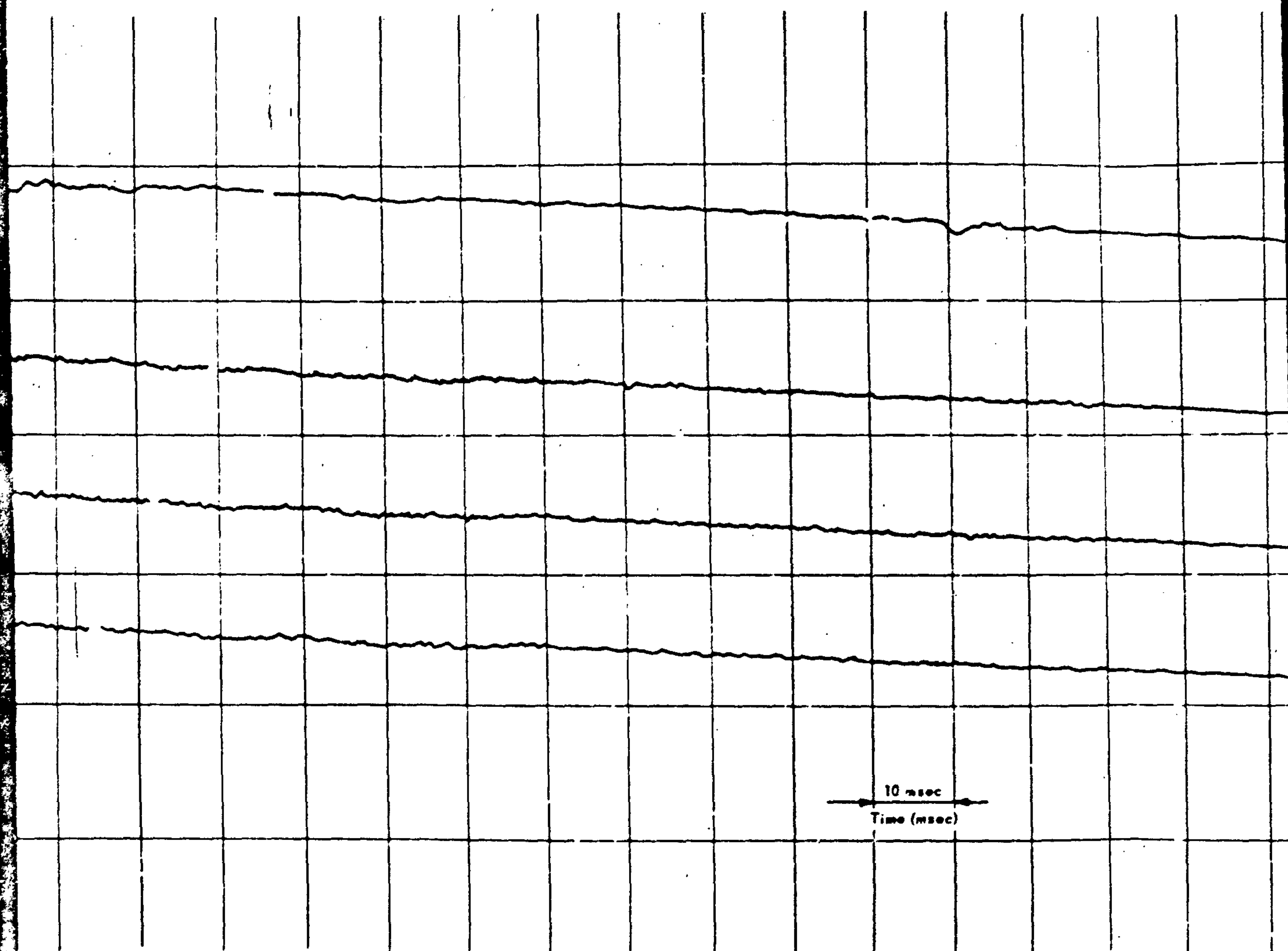
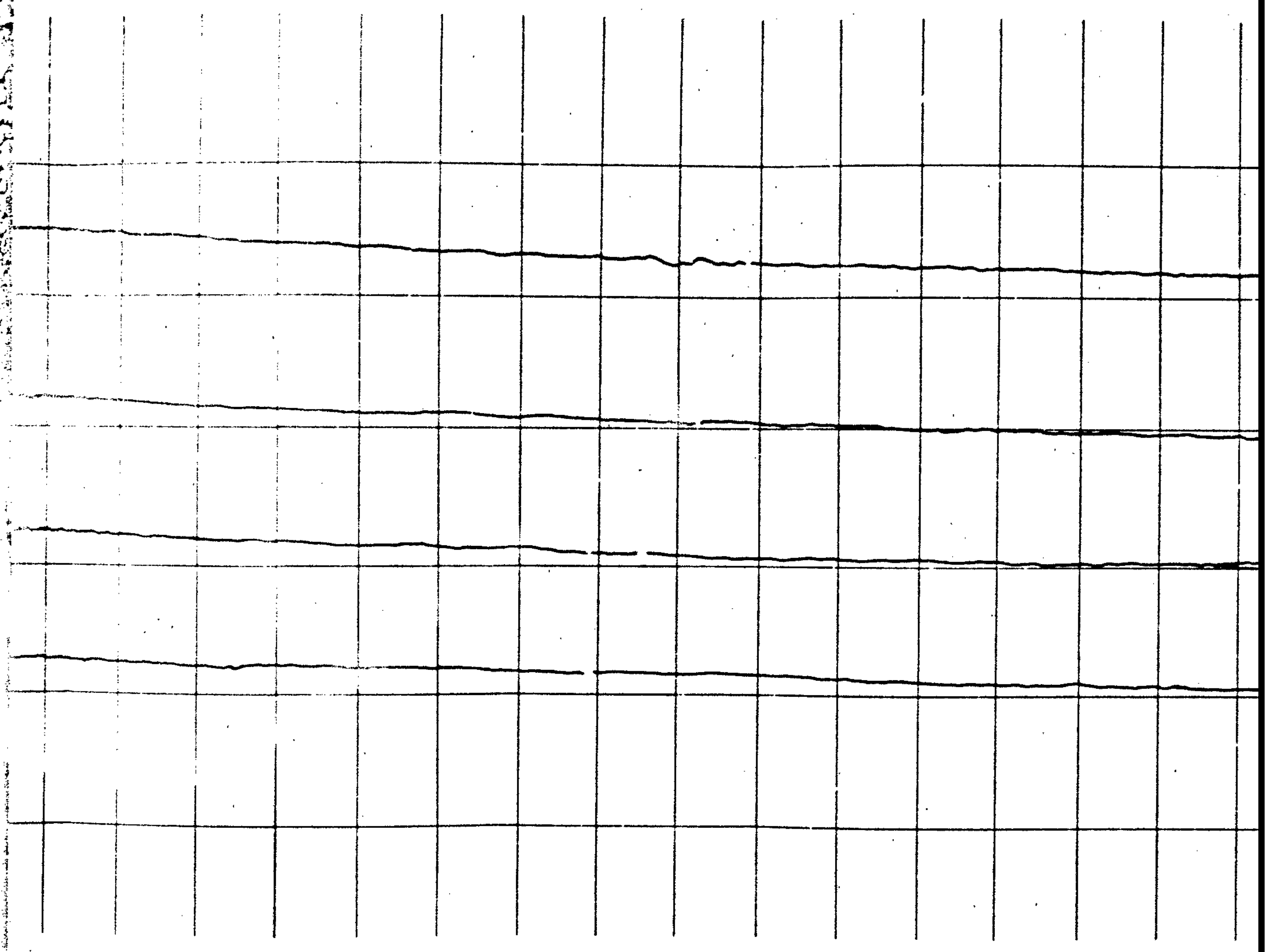


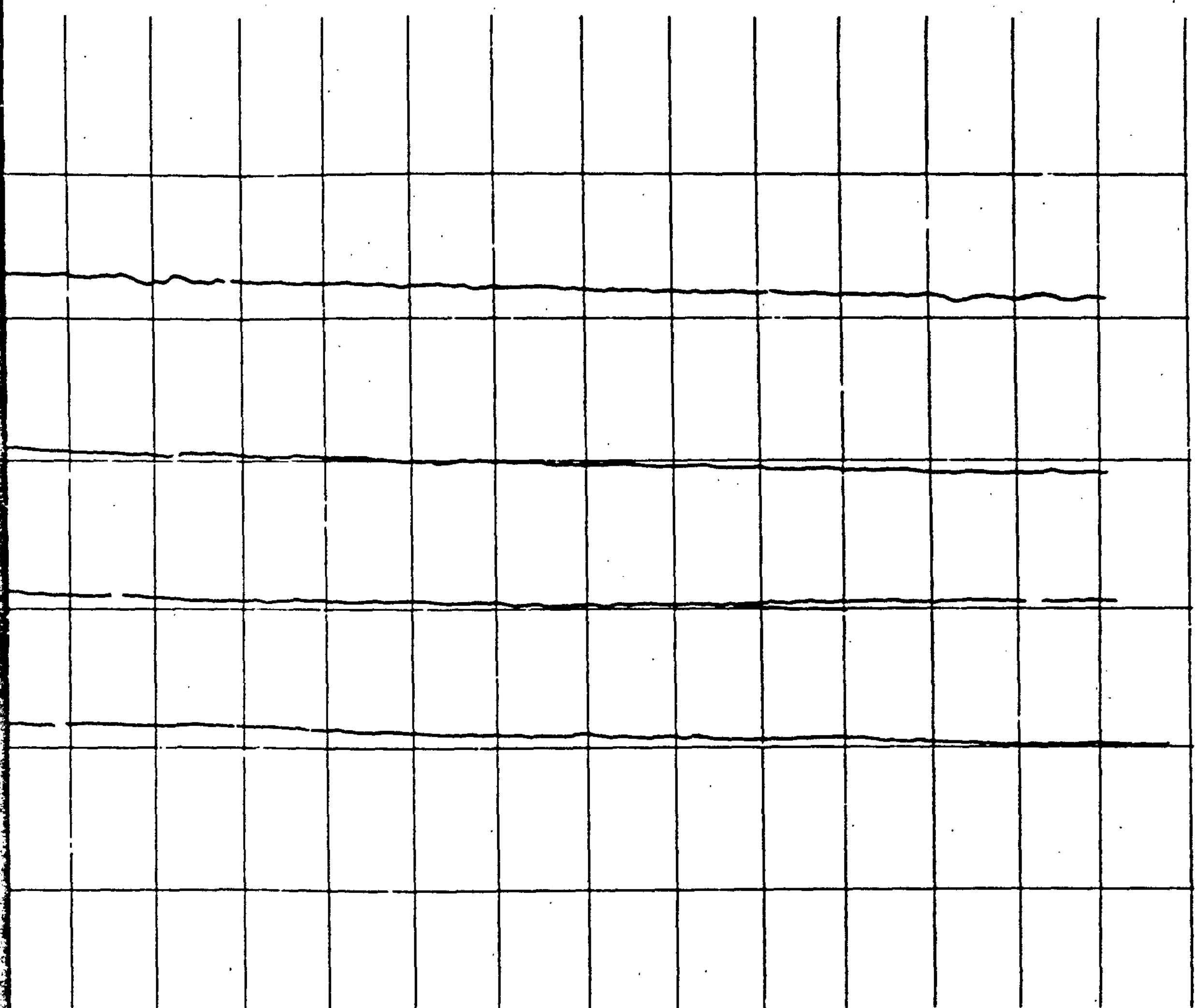
Figure 12b. Overpressure in pit 9 by 18-3/4 inches with four layers of choke.

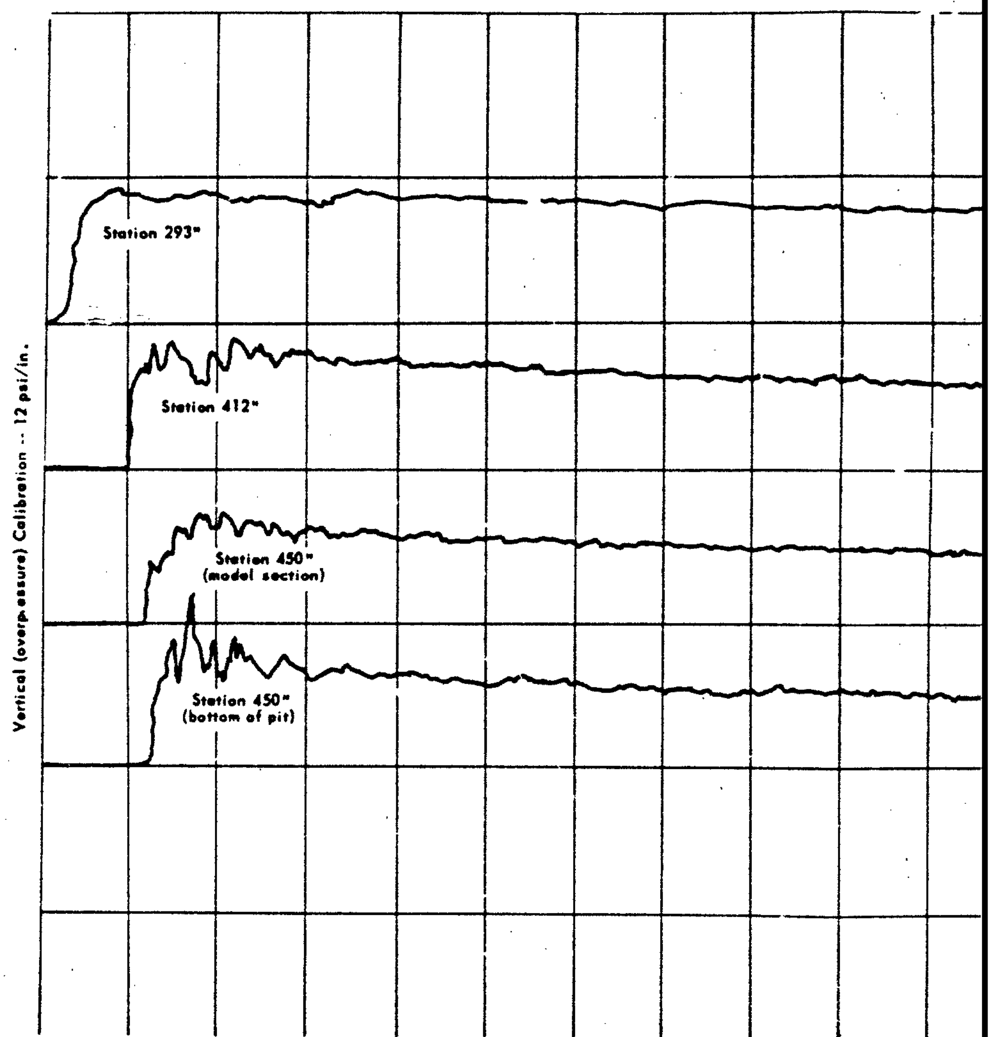
2

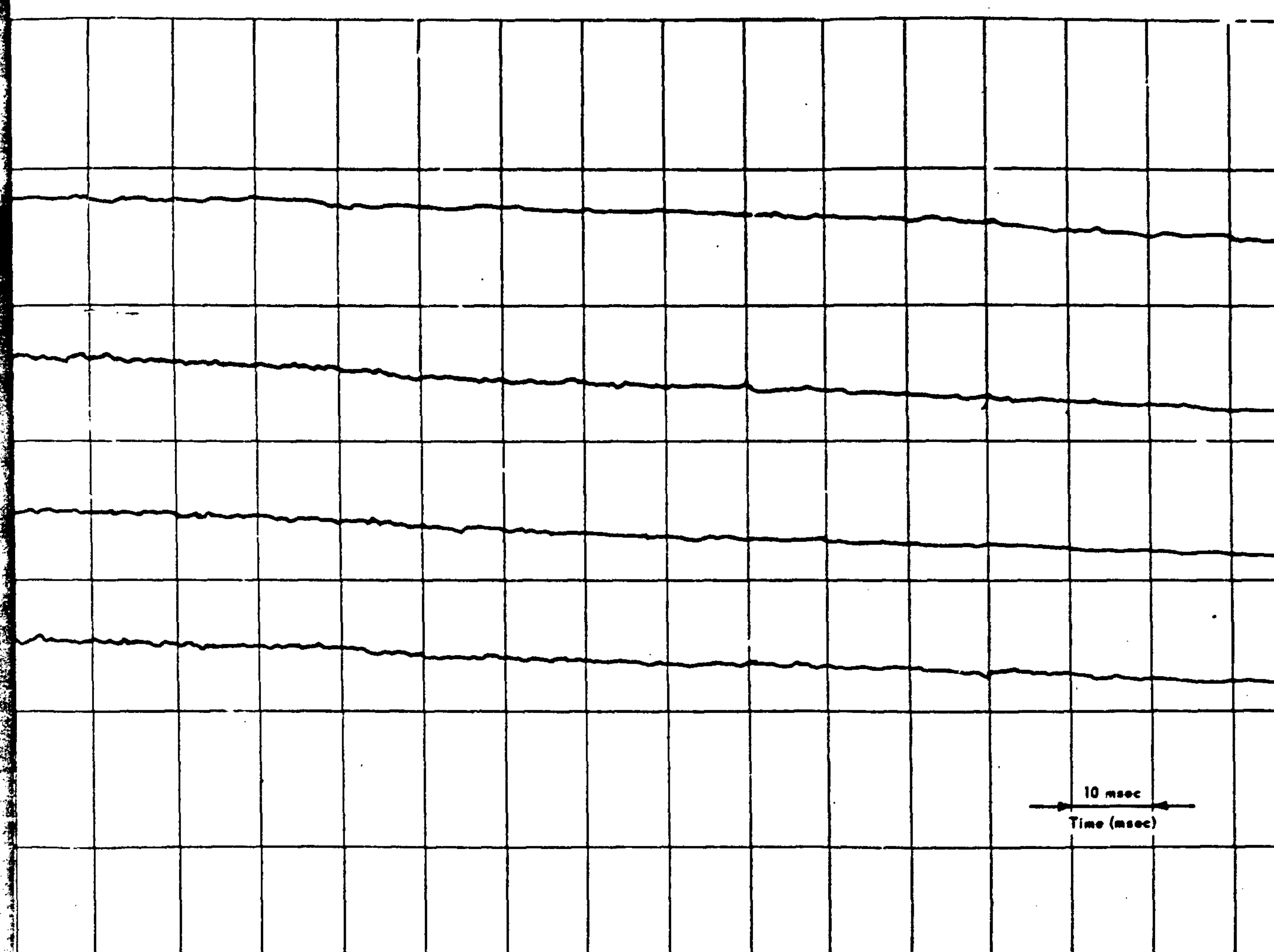


four layers of choke.

3

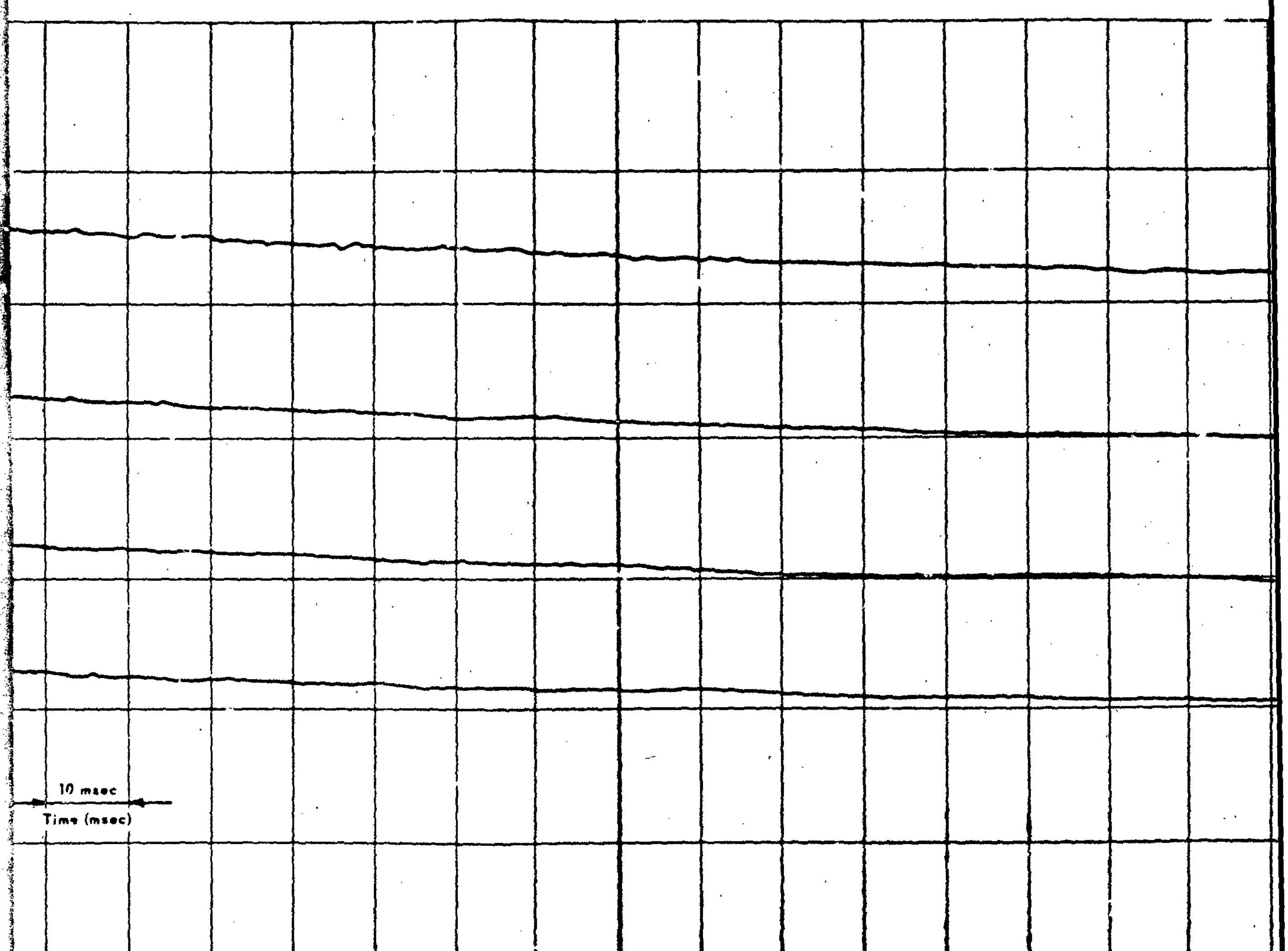



Vertical (overpressure) Calibration -- 12 psi/in.
Station 293"
Station 412"
Station 450"
(model section)
Station 450"
(bottom of pit)



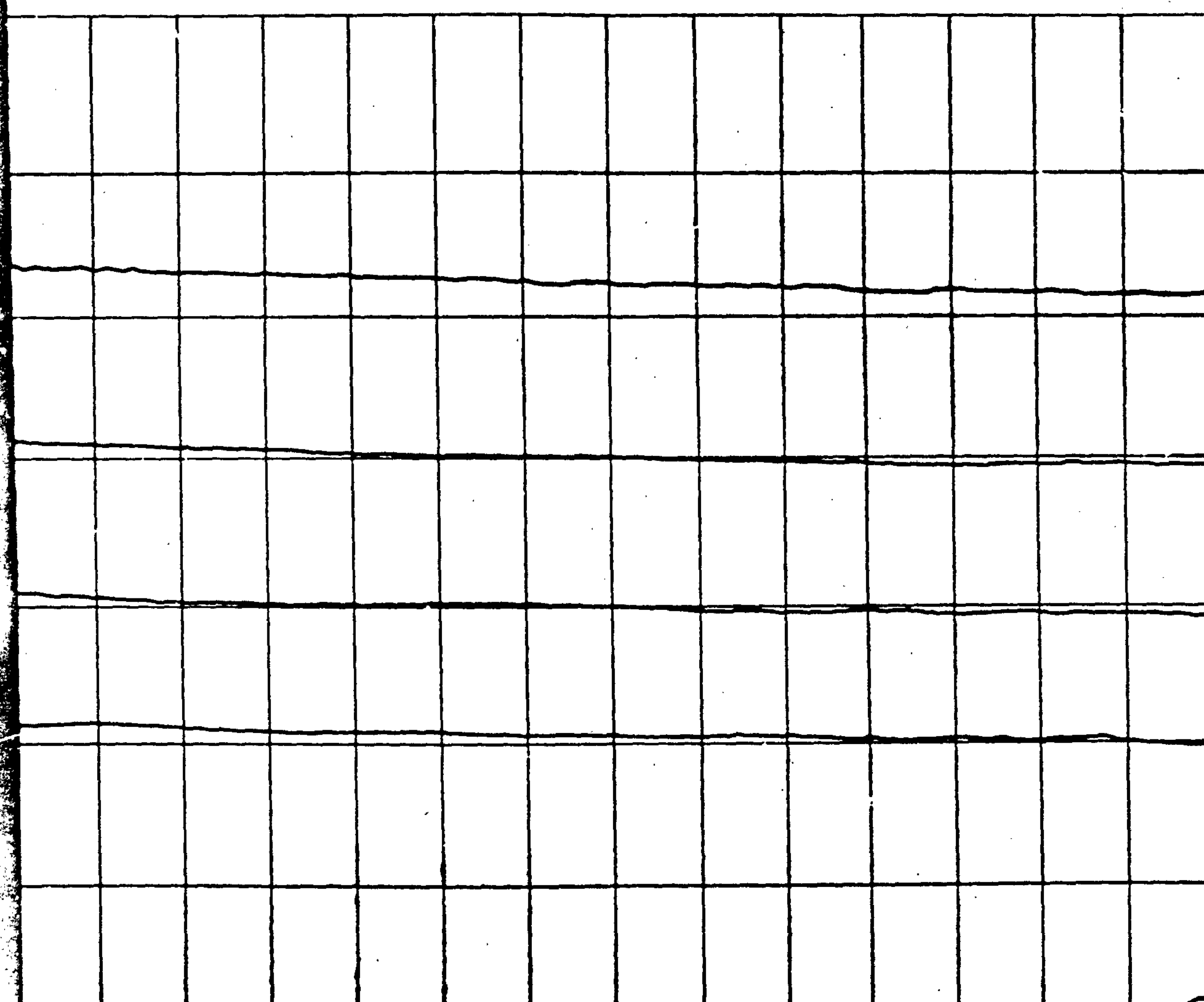
2

Figure 13a. Overpressure in pit 9 by 18-3/4 inches usin

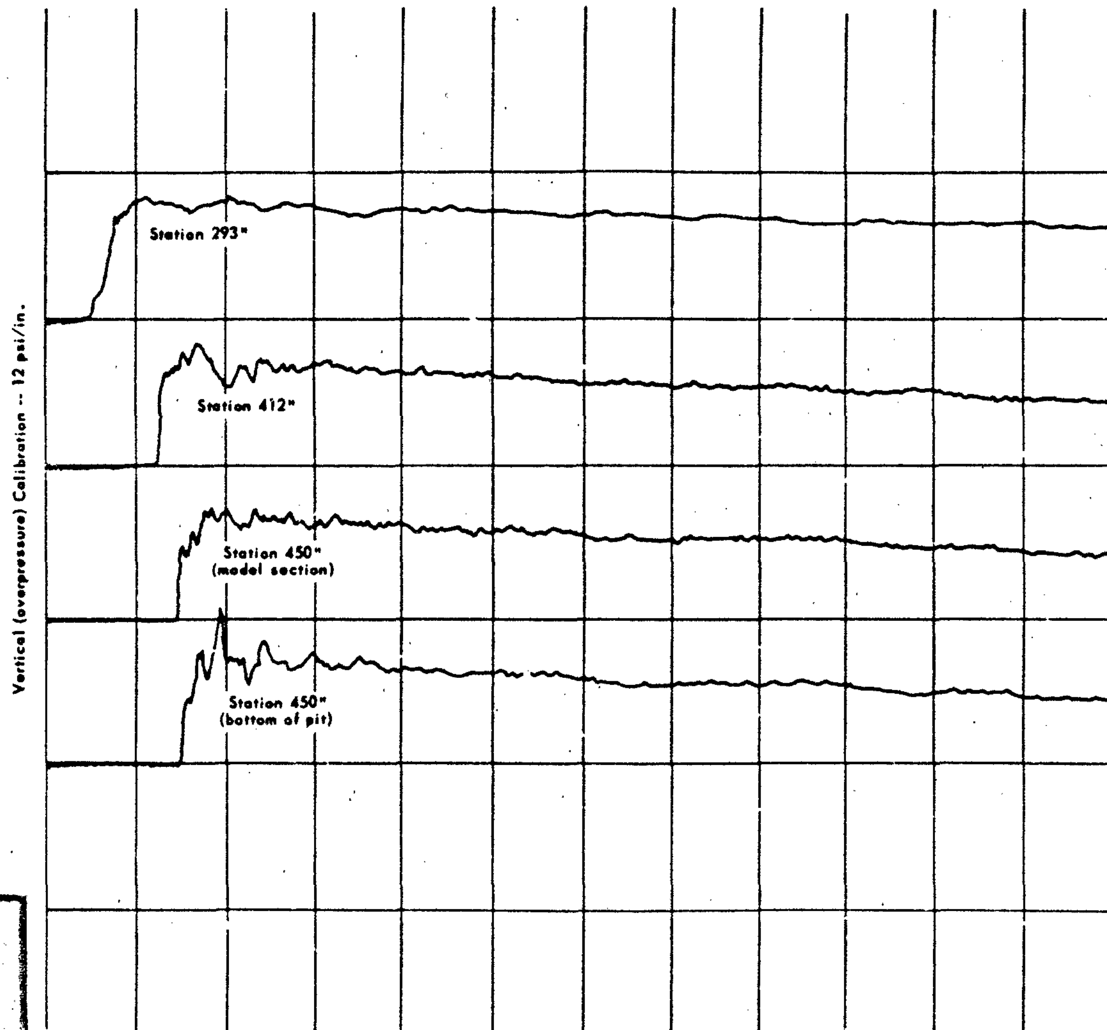


t 9 by 18-3/4 inches using double-ramp parapet.

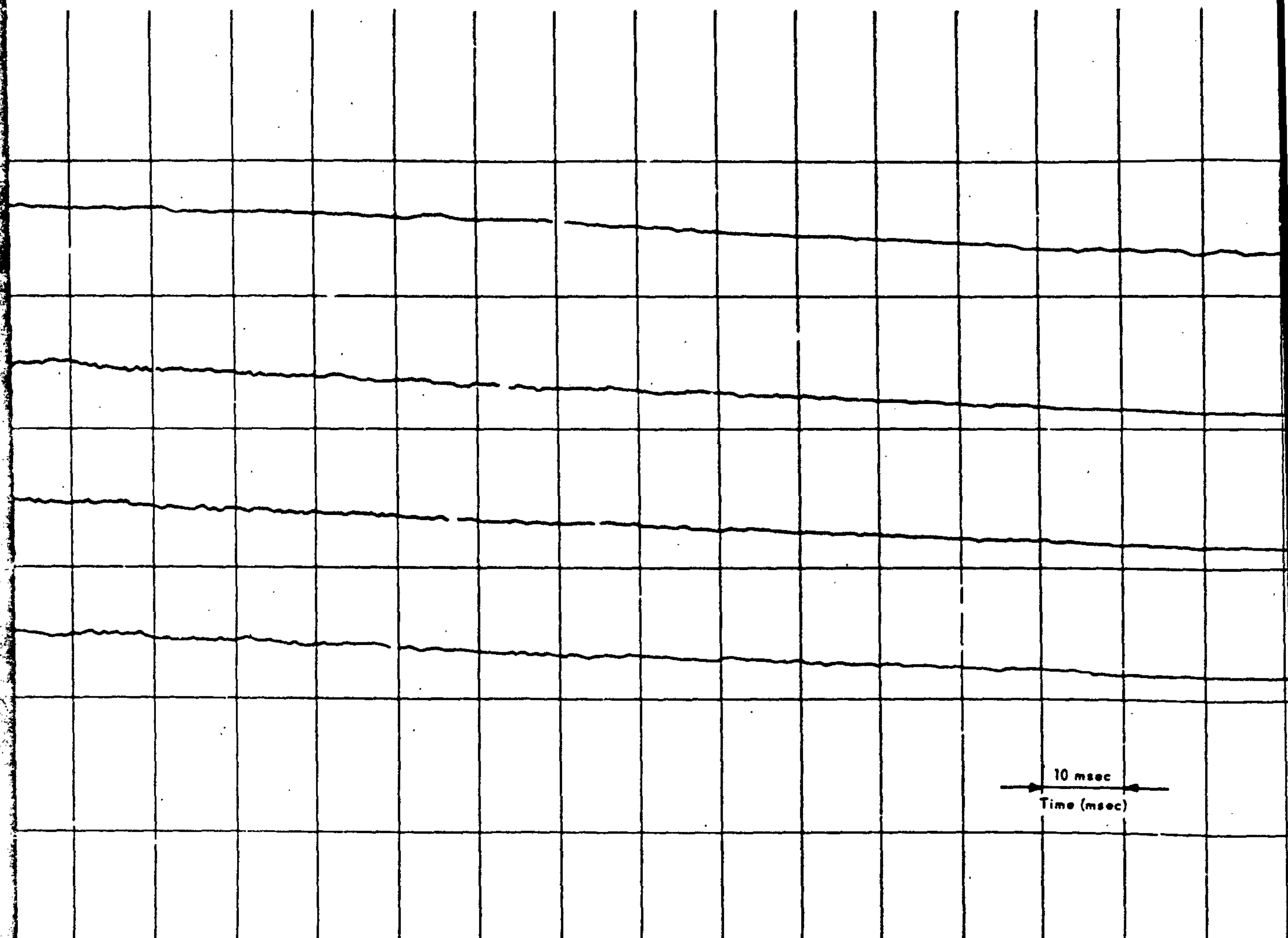
3



4

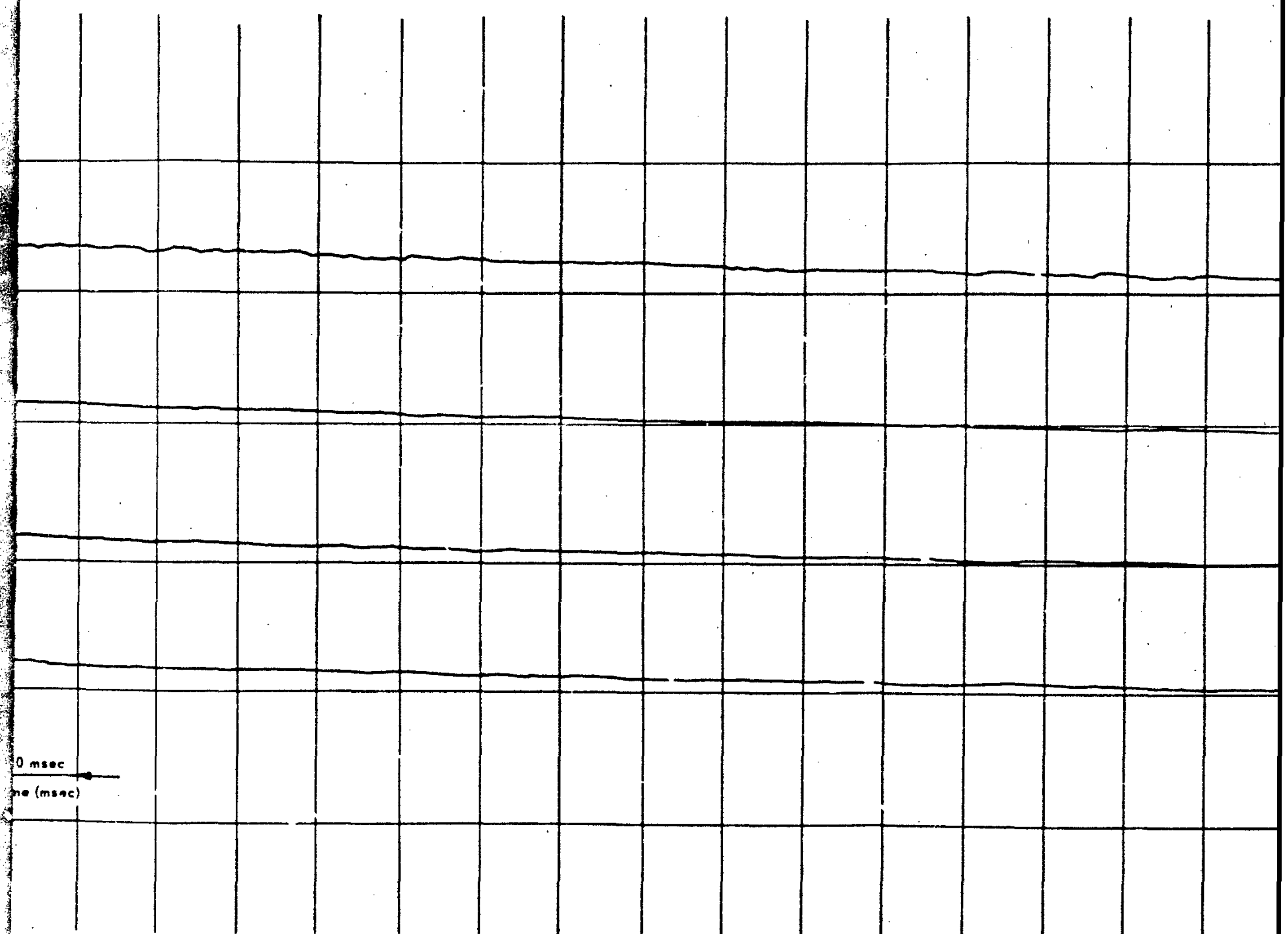


Vertical (overpressure) Calibration -- 12 psi/in.
Station 293"
Station 412"
Station 450"
(model section)
Station 450"
(bottom of pit)



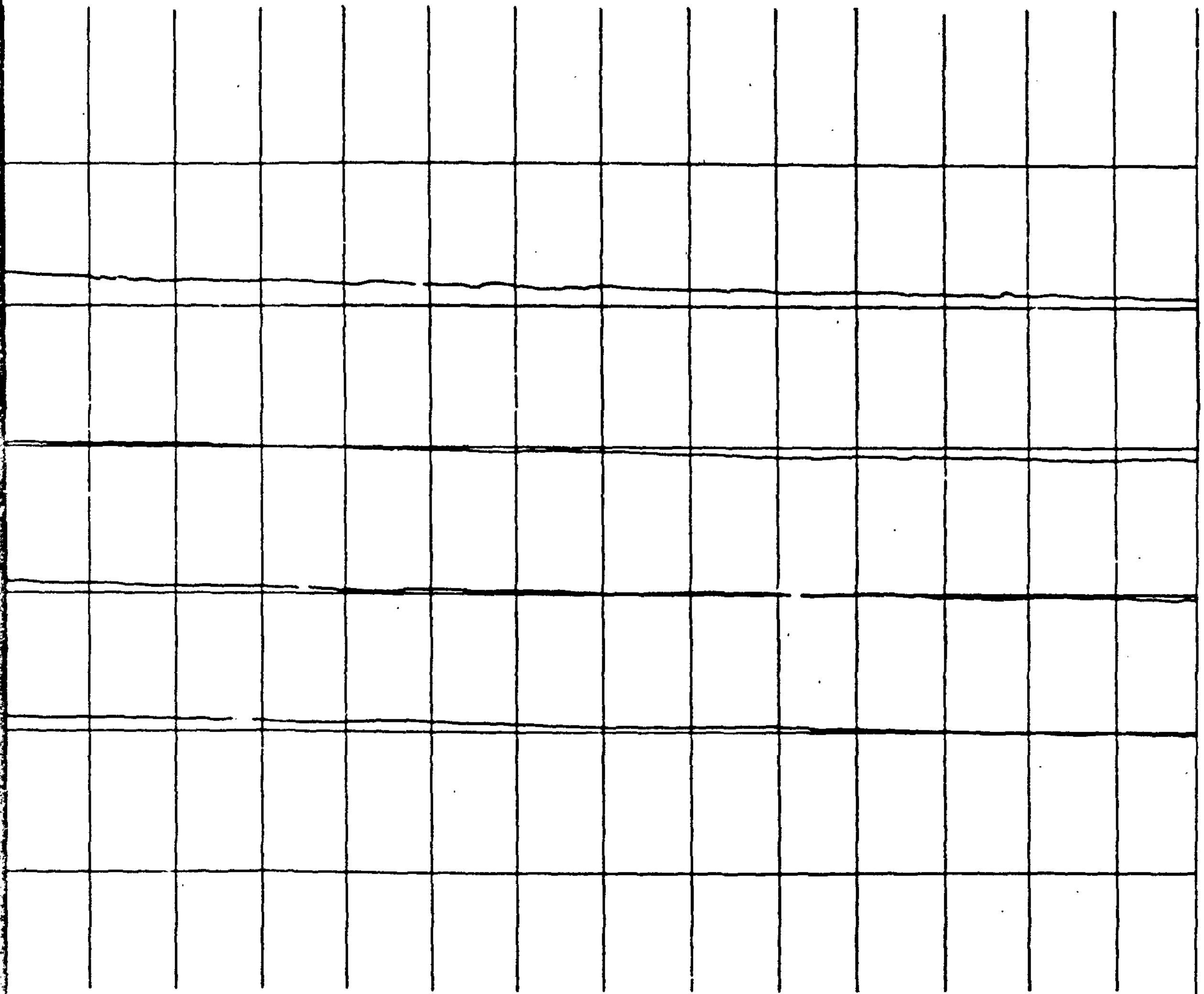
2

Figure 13b. Overpressure in pit 9 by 18-3/4 inches using cover of

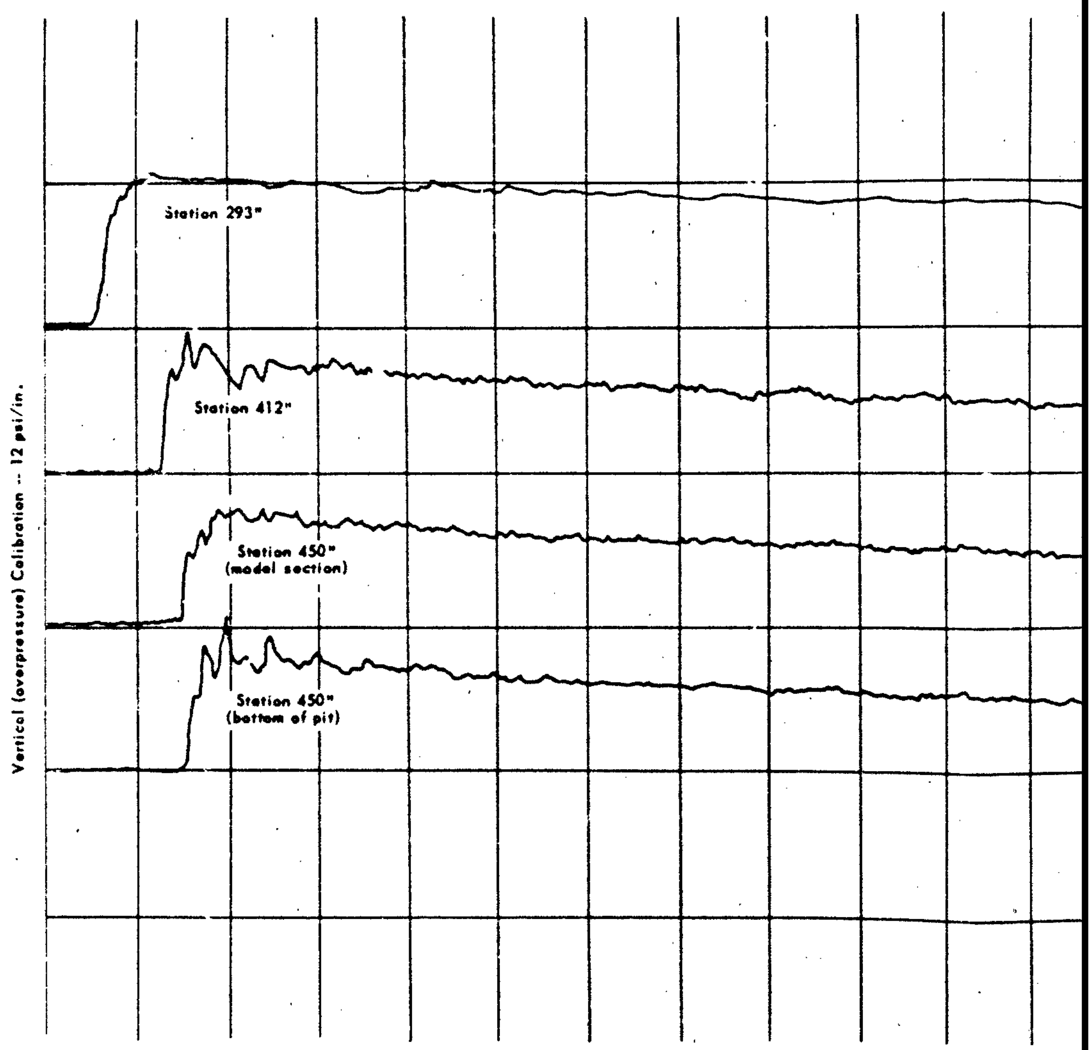


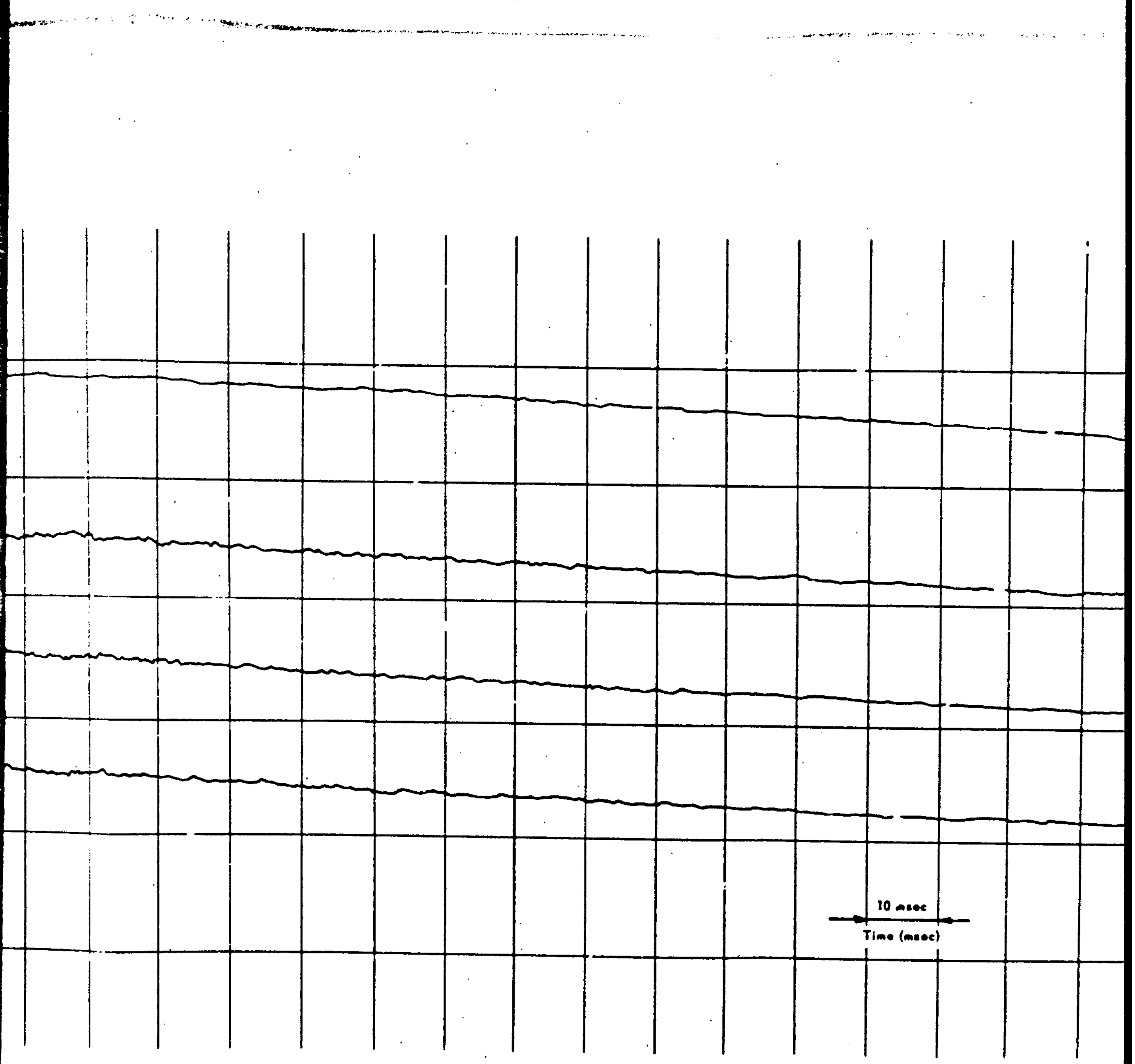
3/4 inches using cover of small holes (A/A_r : 0.62).

3



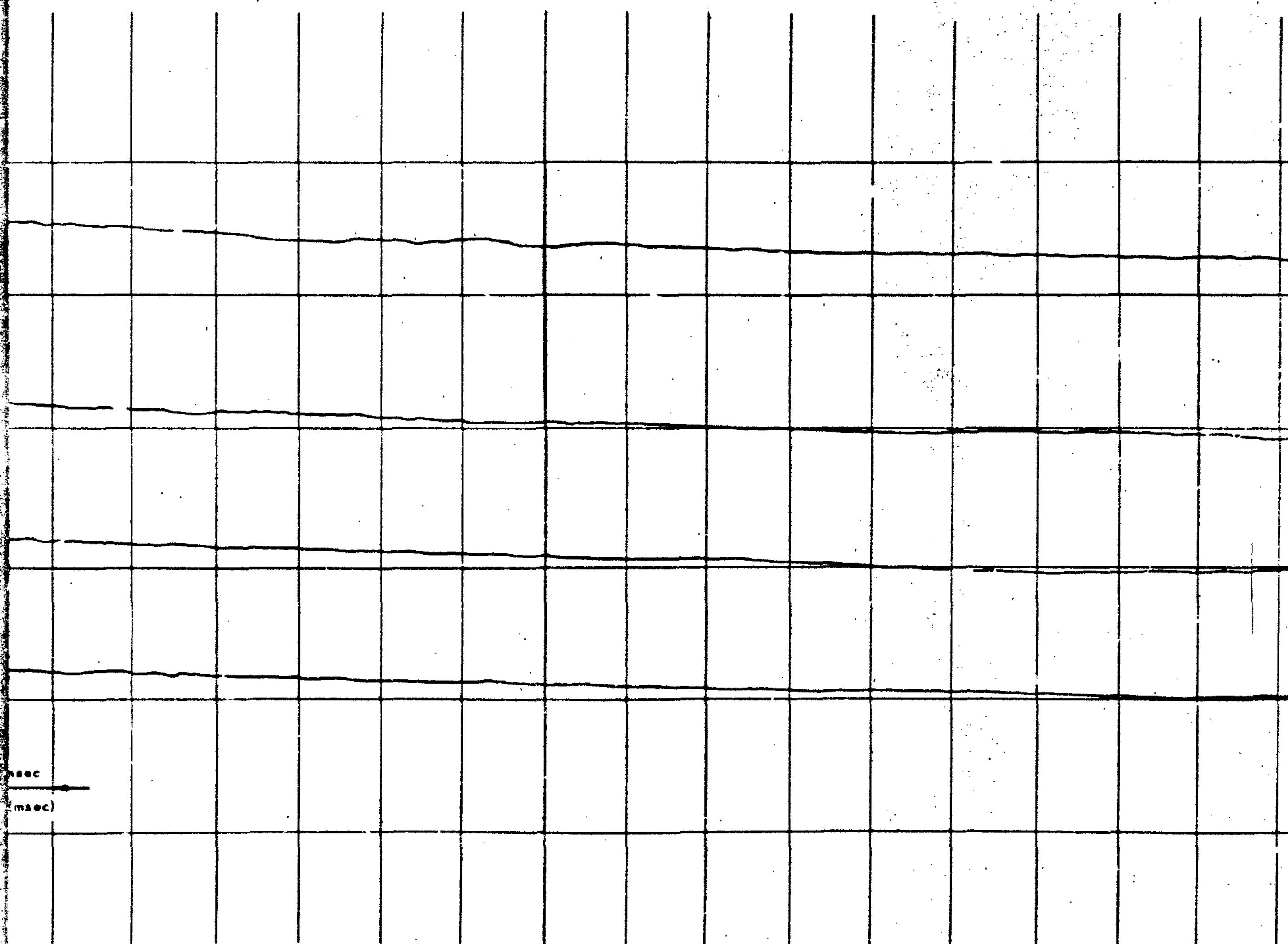
4


Vertical (overpressure) Calibration -- 12 psi/in.
Station 293"
Station 412"
Station 450"
(model section)
Station 450"
(bottom of pit)



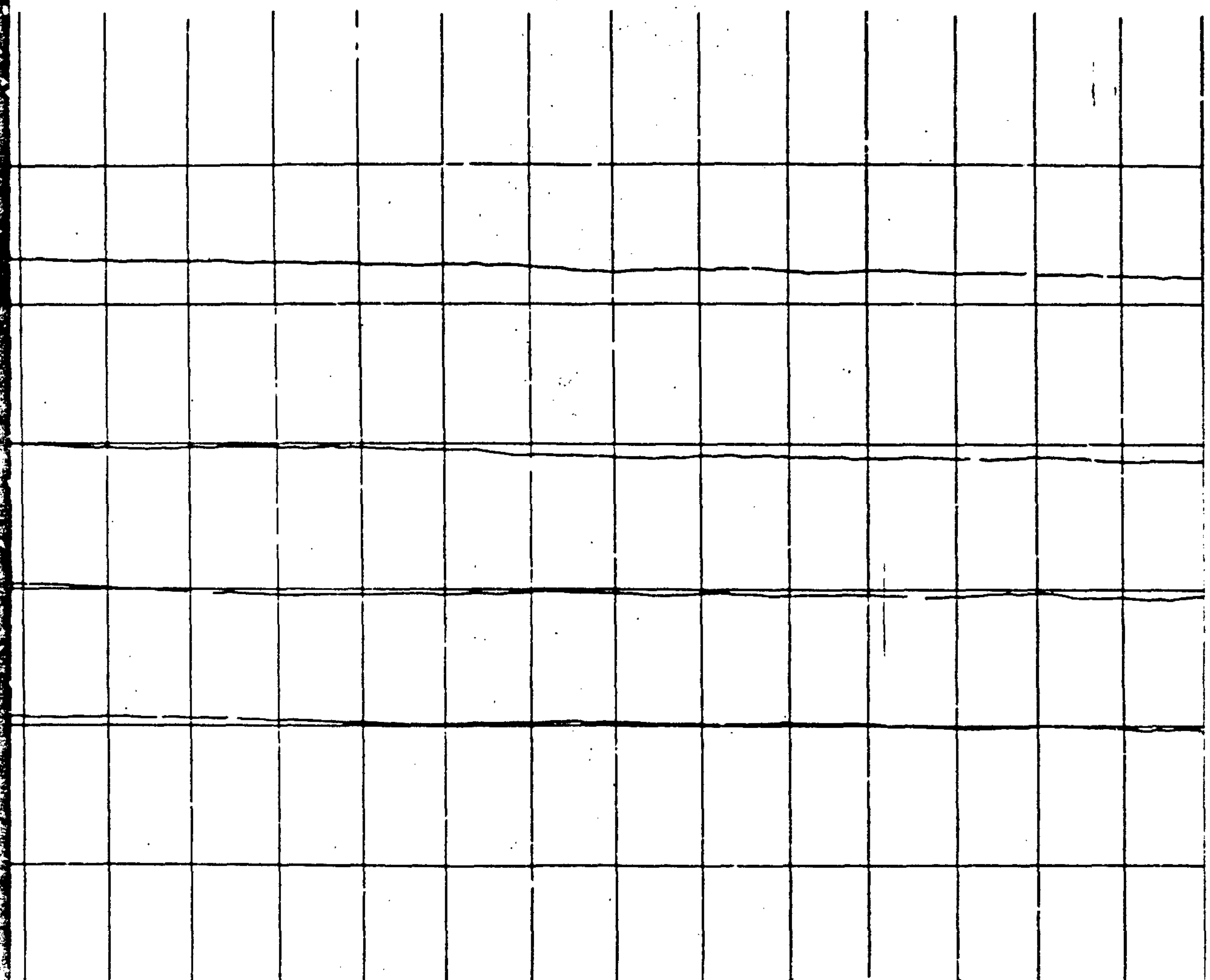
2

Figure 13c. Overpressure in pit 9 by 18-3/4 inches using the reproduced



inches using the reproduced grating (A/A_o = 0.80).

3



4

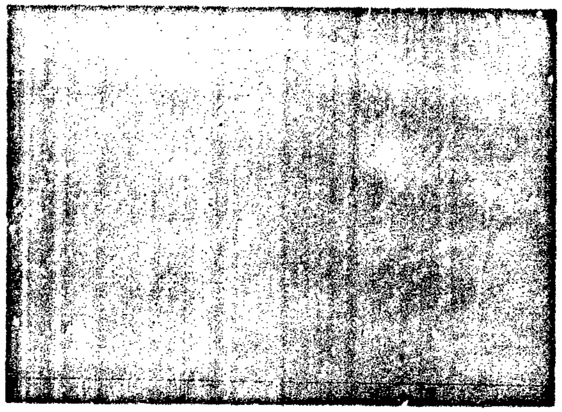


Figure 14a. Dynamic pressure in pit 9 by 18-3/4 inches; no parapets or covers.

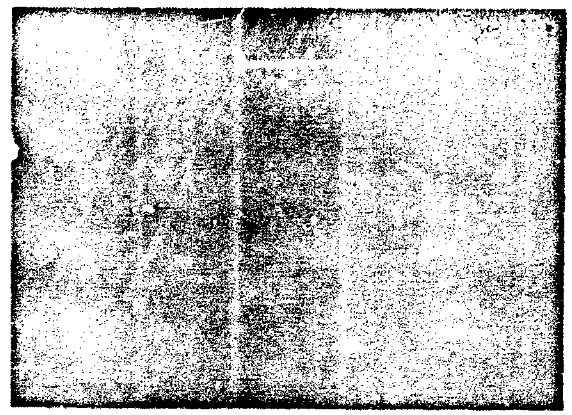


Figure 14b. Dynamic pressure in pit 9 by 18-3/4 inches; double-ramp parapet surrounding pit.

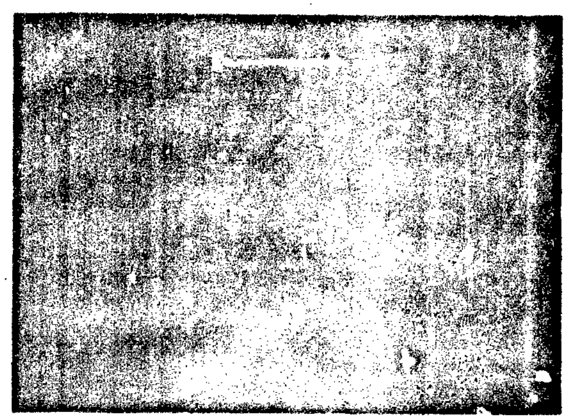


Figure 14c. Dynamic pressure in pit 9 by 18-3/4 inches; 1-1/4 inch lip around edge (A/A_o = 0.62).

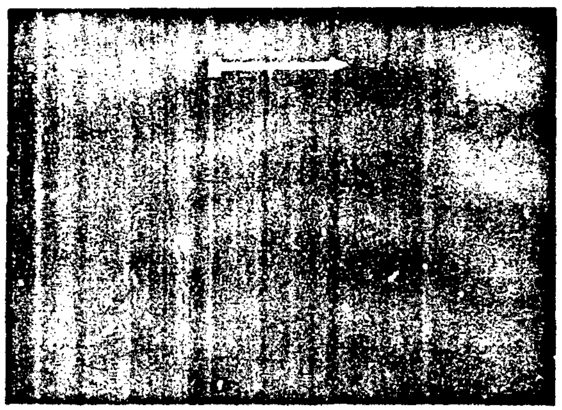


Figure 15a. Dynamic pressure in pit 9 by 18-3/4 inches; cover with eight rectangular openings (A/A_o = 0.62).

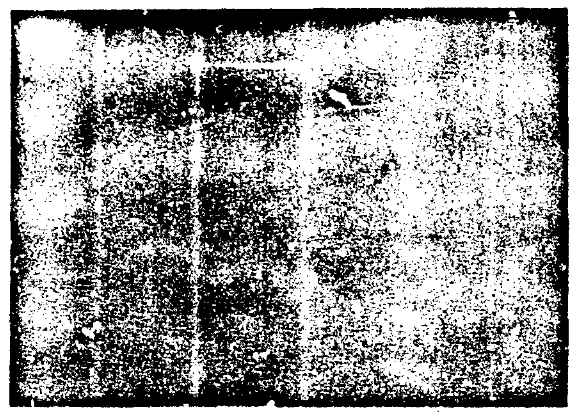


Figure 15b. Dynamic pressure in pit 9 by 18-3/4 inches; cover with small holes (A/A_o = 0.62).

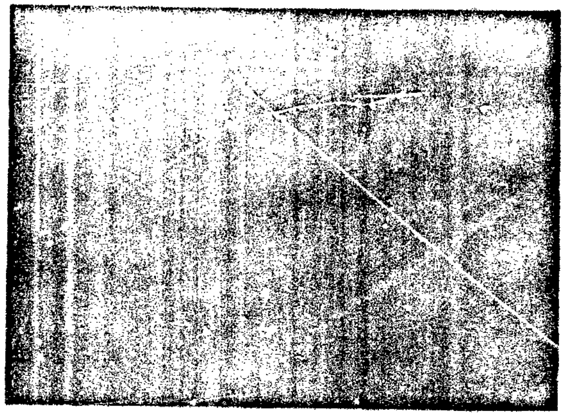


Figure 16a. Dynamic pressure in pit 9 by 18-3/4 inches; flat louvre, frontwise (A/A_o = 0.62).

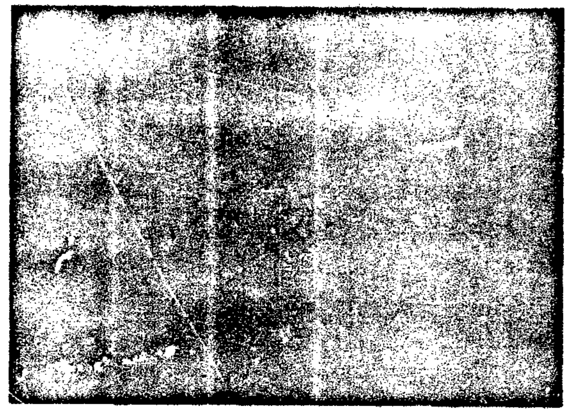


Figure 16b. Dynamic pressure in pit 9 by 18-3/4 inches; flat louvre, sidewise (A/A_o = 0.62).

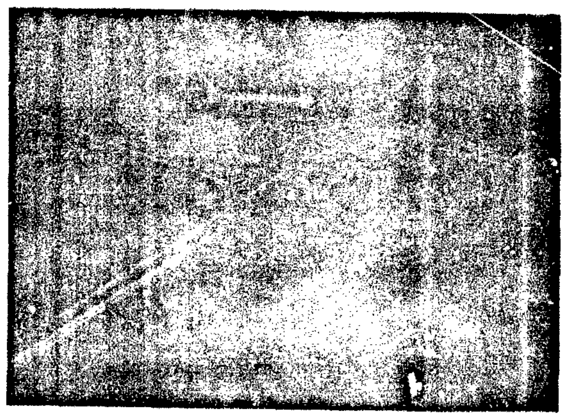


Figure 16c. Dynamic pressure in pit 9 by 18-3/4 inches; flat louvre, backwards (A/A_o = 0.62).

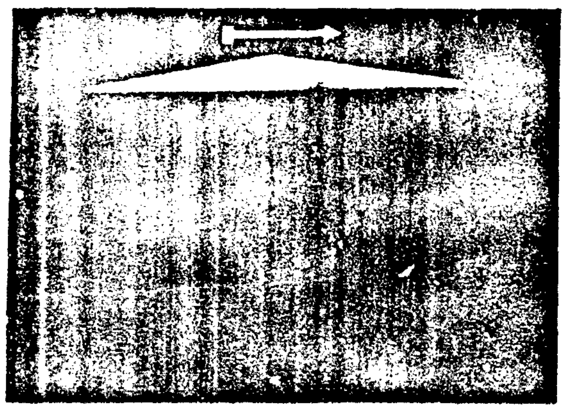


Figure 17a. Dynamic pressure in pit 9 by 18-3/4 inches; pyramid louvre, lengthwise (A/A_o = 0.62).

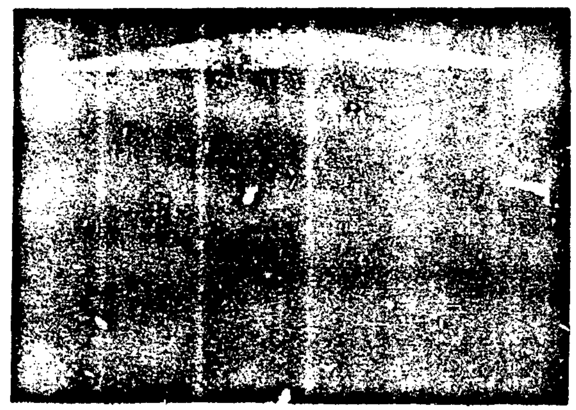


Figure 17b. Dynamic pressure in pit 9 by 18-3/4 inches; pyramid louvre, sidewise (A/A_o = 0.62).

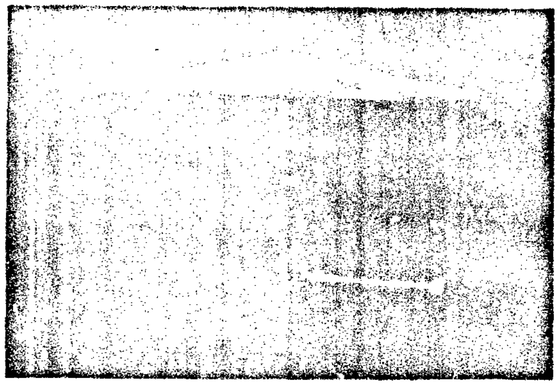


Figure 18a. Dynamic pressure in pit 9 by 18-3/4 inches; pyramid louvres, blast-edge-on, wires on right side (A/A_o = 0.62).

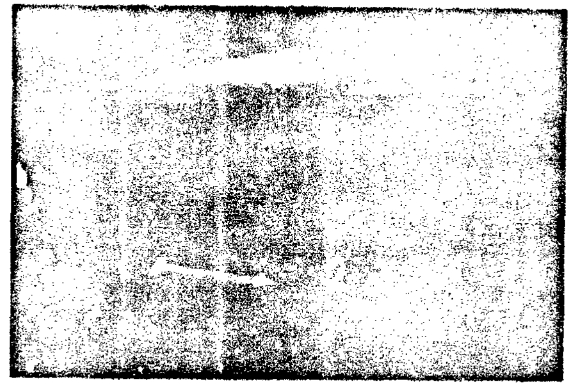


Figure 18b. Dynamic pressure in pit 9 by 18-3/4 inches; pyramid louvres, blast-edge-on, wires on left side (A/A_o = 0.62).

Figure 18c. Dynamic pressure in pit 9 by 18-3/4 inches; pyramid louvres, blast-edge-on, wires on bottom and end (A/A_o = 0.62).

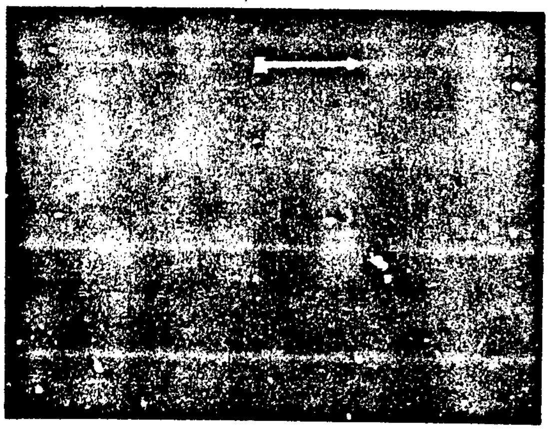


Figure 19a. Dynamic pressure in pit 9 by 18-3/4 inches; grating lengthwise, wires on side (A/A_o = 0.80).

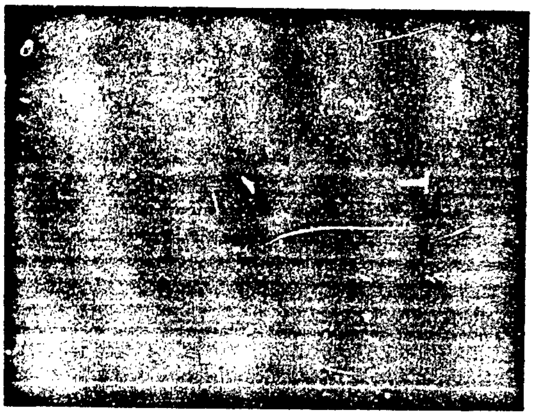


Figure 19b. Dynamic pressure in pit 9 by 18-3/4 inches; grating crosswise, wires on end (A/A_o = 0.80).

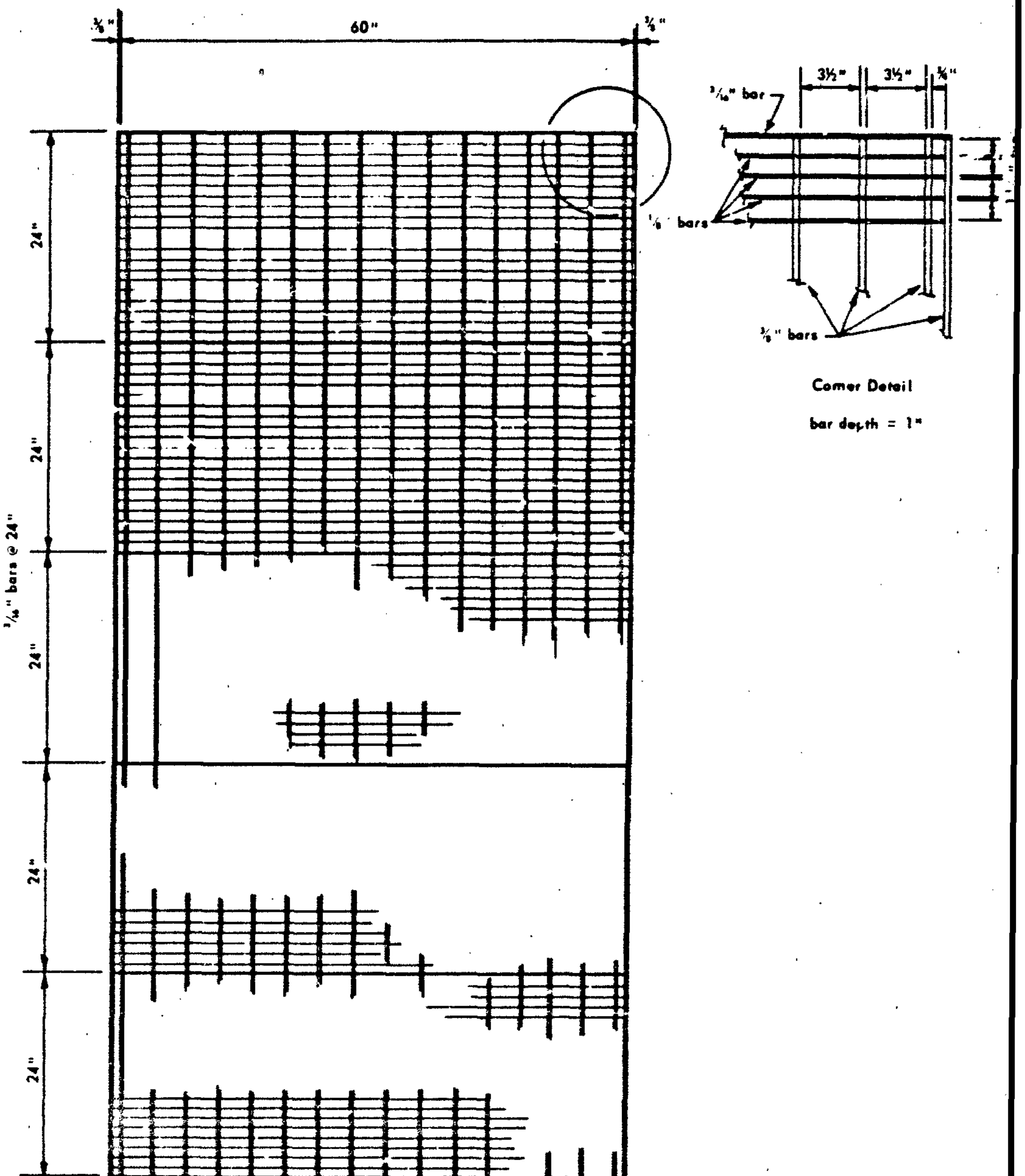


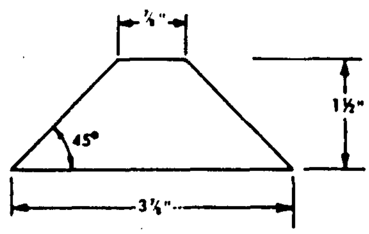
Figure 20. Prototype grating reconstructed from Nevada Test photos and drawings[1] (typical section detailed).

Appendix A

DESIGN OF THE VARIOUS PARAPETS AND COVERS

1. Double-Ramp Parapets (Figure 4b). These surrounded the pit and were located on the edge.

Cross Sections

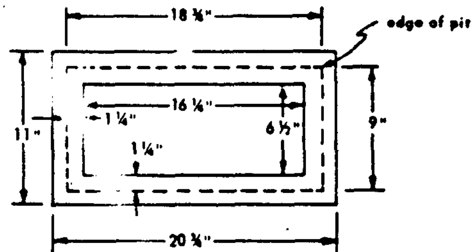


Area ratio A/A_o = 1.00

A = total area of cover or attachment openings

A_o = area of pit opening

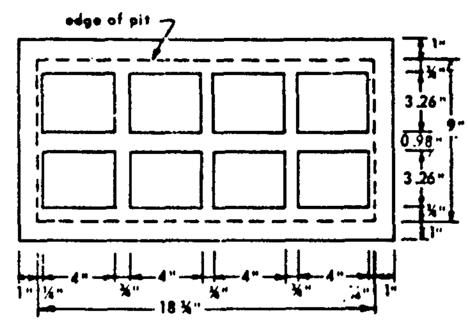
2. Cover With Lip (Figure 4c).



thickness = ¼"

Area ratio A/A_o = 0.62

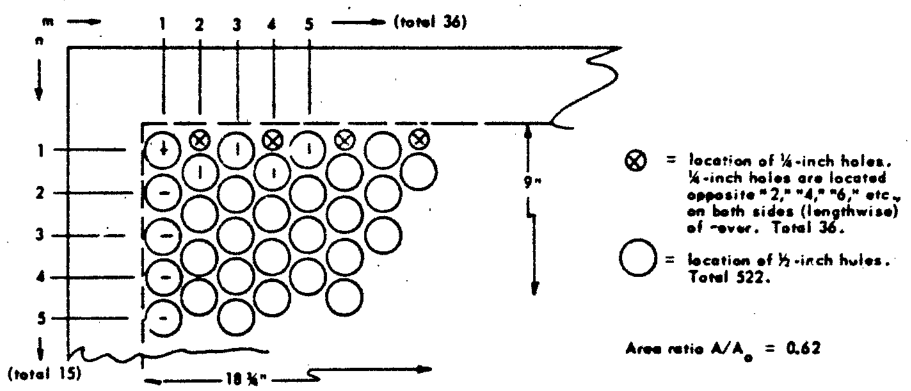
3. Cover With Rectangular Openings (Figure 4d).



thickness = ¼"

Area ratio A/A_o = 0.62

4. Grating With Holes (Figure 5a).



5. Flat Louvres (Figure 5b).

Louvre width, 1-3/16 inches wide, symmetrical about reference plane

Number of louvre openings = 24

Thickness of louvres = 1/16 inch

Spacing between louvres (measured along horizontal plane) = 0.665 inch

Louvre angle with horizontal = 45^o

Ribs: Two, longitudinal, each 1/16 inch thick, placed so as to divide the louvre system into three longitudinal sections

Area ratio A/A_o = 0.62

6. Louvre Pyramid (Figure 5c).

Short faces had 9-inch bases

Long faces had 18-3/4-inch bases

Number of louvre openings = 9 (each face)

Thickness of louvres = 1/16 inch

Spacing between louvres measured parallel to face = 0.988 inch (short face) and 0.454 inch (long face)

Thickness of braces = 1/16 inch

Louvre angle with horizontal = 65° (both faces)

Louvre angle with plane of face = 50° (short face) and 35°50' (long face)

Pyramid angle with horizontal = 15° (short face) and 29°10' (long face)

Width of louvres = 1 inch, symmetrical about plane of face

Area ratio A/A_o = 0.62

7. Grating (Figure 5d and Figure 20)

The dimensions were estimated from the photographs in Reference 1, and may be obtained by dividing those shown in Figure 20 by 5.4.

Appendix B

MODEL JUSTIFICATION

The approach to the model study was based on that in Reference 5. The pertinent quantities are:

Number (i)	Symbol	Pertinent Quantity	Dimensions 1/	Scale Factor 2/ (a_i)
1	P	Pressure in pit	FL^{-2}	1
2	Q	Pressure of applied shock	FL^{-2}	1
3	λ	Linear geometrical factor (length, depth, etc.)	L	n
4	τ	Duration of impulse	T	n
5	v	Velocity of shock	LT^{-1}	1
6	u	Velocity of particles	LT^{-1}	1
7	T	Temperature	θ	1
8	R	Gas constant	$FM^{-1}\theta^{-1}L$	1
9	ρ	Density of air	ML^{-3}	1
10	μ	Viscosity of air	$ML^{-1}T^{-1}$	1
11	e	Bulk modulus	FL^{-2}	1
12	v_s	Velocity of sound	LT^{-1}	1

1/ Dimension symbols:

F = Force
L = Length
T = Time
M = Mass
θ = Temperature

2/ The determination of scale factors is shown later in the dsicussion.

There are twelve pertinent quantities and only five dimensions; therefore, seven Pi terms are required. Further, certain quantities must scale the same in the model as in the prototype. These quantities are temperature, gas constant, density of air, viscosity of air, bulk modulus, and velocity of sound. Also, the geometrical factors scale by n, the arbitrary scale factor that determines the relative size of the prototype and the model.

The following Pi terms apply. "α" refers to the scale factor for the quantity whose number (from the list of pertinent quantities) is indicated by the subscript. Thus, "α_5" is the scale factor for velocity of shock.

Dimensional Analysis

Pi Term Number	Algebraic Form	Dimensional Form	Scale Factor
1	$\frac{P}{Q}$	$\frac{FL^{-2}}{FL^{-2}} = 1$	$\frac{\alpha_1}{\alpha_2} = 1$
2	$\frac{\lambda}{Tv}$	$\frac{L}{T(LT^{-1})} = 1$	$\frac{\alpha_3}{\alpha_4\alpha_5} = 1$
3	$\frac{v}{u}$	$\frac{LT^{-1}}{LT^{-1}} = 1$	$\frac{\alpha_5}{\alpha_6} = 1$
4	$\frac{RT\rho}{Q}$	$\frac{(FM^{-1}\theta^{-1}L)(\theta)(ML^{-3})}{FL^{-2}} = 1$	$\frac{\alpha_8\alpha_7\alpha_9}{\alpha_2} = 1$
5	$\frac{e}{Q}$	$\frac{FL^{-2}}{FL^{-2}} = 1$	$\frac{\alpha_{11}}{\alpha_2} = 1$
6	$\frac{\rho v \lambda}{\mu}$	$\frac{(ML^{-3})(LT^{-1})(L)}{ML^{-1}T^{-1}} = 1$	$\frac{\alpha_9\alpha_5\alpha_3}{\alpha_{10}} = 1$
7	$\frac{v}{v_s}$	$\frac{LT^{-1}}{LT^{-1}} = 1$	$\frac{\alpha_5}{\alpha_{12}} = 1$

Since $a_7 = a_8 = a_9 = a_{10} = a_{11} = a_{12} = 1$, and $a_3 = n$, the following equations are obtained:

1. $a_1 = a_2$

2. $a_3 = a_4 a_5 = n$

3. $a_5 = a_6$

4. $a_8 a_7 a_9 = a_2 = 1$

5. $a_{11} = a_2 = 1$

6. $a_9 a_5 a_3 = a_{10}$; $n(a_5) = 1$

7. $a_5 = a_{12} = 1$

From these equations (excluding Equation 6) it follows that:

$$a_1 = 1, a_2 = 1, a_5 = 1, a_6 = 1 \text{ and } a_4 = n$$

The values of the a's now satisfy all of the Pi terms except number 6, which is the Reynolds' number. Inasmuch as the Reynolds' number in the present study is quite high and its effect is more or less constant above 100, it makes little difference if Pi term number 6 is scaled or not. It is impractical to scale the Reynolds' number, and the foregoing provides a reasonable approximation (Reference 5, Article 73, pages 158-159).

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Key Words: blast protection; dynamic pressure; generator protection; model studies; shelter design; shock protection; shock tube

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